Interventional Critical Care

A Manual for Advanced Practice Providers

Dennis A. Taylor
Scott P. Sherry
Ronald F. Sing
Editors

Second Edition

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Foreword

Rapid expansion underscores key changes in how – and where – critical care medicine is practiced. Perhaps the most striking change that has occurred is in team composition. Pivotal and anchoring roles for Advanced Practice Providers (APPs) have emerged in daily workflow as well as diagnostic and therapeutic procedures. Ultrasound and endoscopy feature prominently in diagnostic and therapeutic undertakings; both are complemented by fluoroscopy as well. This second edition of *Interventional Critical Care: A Manual for Advanced Practice Providers* offers well-written, succinct, and informative chapters spanning team composition to procedural competency. Clear instruction supplemented by ample high-quality images illustrate essential principles and steps to guide APPs through commonly required critical care procedures. Whether new to practice or well established in a critical care space spanning the emergency department to a general or specialty intensive care unit, this book provides a foundation upon which practice may rest or be expanded. Regardless of the patient type on which your critical care unit focuses, the procedures your patients will require are housed in this comprehensive text. I am certain that the second edition will be a critical tool in the APPs armamentarium in the pursuit of critical care excellence.

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Preface

The goal of the first edition of *Interventional Critical Care – A Manual for Advanced Practice Providers* was to fill a knowledge gap of the advanced practice provider (APP) specifically regarding the skills and understanding of critical care procedures in response to the rapidly expanding participation of APPs in critical care. When we were asked by the publisher to produce a second edition, we paused for period of time to consider what a second edition would contribute that the first edition missed. Moreover, what would we be contributing regarding procedures that are relatively unchanged?

What we learned was actually from feedback by the many physicians, APP providers, *and* especially APP learners who have used the first edition, many in settings outside the ICU: critical care interventions/procedures are not limited to the ICU. Critical care occurs in all areas of healthcare environments, from the emergency department to the floors (i.e., acute events), to the post-anesthesia units, and so on. So, in response, we have eliminated a few non-essential chapters with minimal use and added a number of chapters expanding on more common but necessary procedures used in the critical care setting. In addition to our original model to illustrate the procedures, we've expanded the ultrasonography areas to include more direct hemodynamic evaluations as well as the newer "e"FAST. Furthermore, we've expanded the urology to include more complex interventions. As billing and coding are necessary, we've also added appropriate CPT codes for each of the appropriate chapters. This second edition adds to the content of the first edition and includes new content and chapters that reflect current practice and procedures. Most chapters have been completely re-written and updated from the first edition and have different authors – thereby a different perspective and experience level. The editors and chapter authors of this text were recruited from facilities and programs from across the USA. They all actively practice in the ICU, OR, and ED and are considered content experts in their respective fields. All chapters are authored by an APP and/or physician. Many authors are also designated as fellows of the American College of Critical Care Medicine (FCCM), having made significant contributions to patient care, and the Society of Critical Care Medicine (SCCM). We hope you will enjoy reading and using this text as a reference in your

daily practice in the ICU, OR, and/or ED setting. It has been a pleasure working with all of the chapter authors and contributors. We express our appreciation to Michael D. Sova and Kevin Wright at Springer Publishing for all of their contributions and work on this project.

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Part I

Administrative Considerations

The Multidisciplinary ICU Team

1

Loretta Rock, Larissa Whitney,
and Frederick B. Rogers

Introduction

Since its birth as a specialty, critical care medicine has only been possible through the coordinated efforts of staff from multiple disciplines. During the Copenhagen polio epidemic of 1952, in which hundreds of patients were first able to be maintained on positive pressure ventilation, it became evident that drafting medical students in shifts for 24-h care was a flawed staffing strategy [1]. To address the problem, mechanical ventilators were adapted to routine use, and the ICU ward with dedicated physician staff, one-to-one nursing care, and physiotherapists was soon established [2]. As technical capabilities have improved, and patients survive ever more complex injuries and diseases, the ICU team has expanded to require not just highly trained nurses, respiratory therapists, and physicians but the specialties of critical care pharmacy, perfusion, physical and occupational therapy, nutrition, and social work. Advanced monitoring and support means procedures previously confined to the operating room can be safely performed in the ICU under a team-guided delivery system. Physician assistants and acute care nurse practitioners, together known as advanced practice providers (APPs), have evolved alongside the specialty, and "intensivist APPs" add value as proceduralists, educators, and providers of periprocedural care [3, 4].

The safe and efficient completion of procedures in the ICU requires forethought and interdisciplinary team preparation. Even emergency procedures reliant on "low-frequency, high-stakes" decision-making can be improved by the utilization of crew resource management communication techniques. Learning the fundamentals of teamwork and collaborative care is paramount to the clinical education of successful healthcare providers and strongly endorsed by the World Health Organization. Researchers have found interdisciplinary teams reduce provider burnout, reduce medical errors, and increase patient safety [5].

Nursing

The role of nursing in the constant monitoring and management of critically ill patients was established in the Crimean War through the creation of the first "SICUs" credited to Florence Nightingale, who gathered the most seriously injured close to the nurse's station for care. These predecessors of our modern ICU laid the groundwork for what, in the 1960s and beyond, would become one of the most highly technical areas of nursing [6]. Through the completion of a rigorous board exam, hours-requirements, and continuing education, nurses

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can achieve certification as a Critical Care Registered Nurse [7]. Today's ICU nurses are typically responsible for the minute-to-minute care of hemodynamic and respiratory status of their patients. Their responsibilities on an ICU procedural team mimic those of the circulating OR nurse (in preparation of the patient, verification of consent, and preparation of the environment and instruments), but they are additionally prepared to respond to changes in vital signs, pain, and sedation. ICU nurses are also key in maintaining the complex relationship between patient, provider, and family. As the clinicians logging the highest number of hours at the bedside, they have a unique perspective on the patient as an individual.

Respiratory Therapy and Perfusion

Registered respiratory therapists (RRT/RCP) have a hands-on role in patient recovery from a wide array of pulmonary disease and are considered experts in respiratory care equipment for the healthcare system. Respiratory therapists work closely with anesthesiologists and intensivists to secure the airway, deliver life-saving treatments, and manage ventilators in critically ill patients. The combination of technical application, patient assessment, troubleshooting, and expertise in complex respiratory conditions makes respiratory therapists crucial members of the periprocedural ICU team.

Once strictly a specialty of the operating room, perfusionists are becoming routine ICU staff in facilities equipped to provide extracorporeal membrane oxygenation (ECMO). The Certified Clinical Perfusionist manages circuits, flows, volume status, and blood gas balance of patients on cardiopulmonary bypass. Before, during, and after insertion of ECMO cannulas, the perfusionist provides highly specialized care of patients in life-threatening circumstances [8].

Rehabilitation Therapy

Occupational therapists, physical therapists, speech language pathologists, and physiatrists join the interdisciplinary team in many ICUs as members tasked with close patient contact that emphasizes the transition from critical illness to recovery. Physiatrists, once relegated to the domain of specialized rehabilitation units, now routinely consult on many aspects of the ICU patient's care including pain regimen, mobility, and cognitive therapy. Further, early evaluation of the ICU patient provides that all-important continuity upon discharge to the rehabilitation unit. Multiple studies have demonstrated that early physiatry evaluation in the ICU phase of care improves outcomes.

Occupational therapists assist patients across the lifespan in activities of daily living, rebuilding the confidence and mobility necessary for continued healing. They complete evaluations of the patient's prior to admission environment and develop treatment plans with adaptive equipment recommendations, guidance, and family/caregiver education. Physical therapists work with patients to improve mobility, restore function, limit or prevent permanent physical disability, and improve pain control. They survey a patient's medical history, test patient performance, and develop treatments to prevent loss of mobility in critically ill patients before it occurs.

Speech language pathologists work with patients that are at risk for, or have developed, dysphagia, dysphonia, or cognitive deficits related to language and expression. They regularly diagnose, treat, and provide recommendations for aspiration prevention. Specific to critical care, they are integral in assessing which patients may benefit from PEG tube and facilitating the gradual regain of speech and removal of tracheostomy tube in patients recovering from respiratory failure [9].

Pharmacy

In 2013, an international panel funded by the Agency for Healthcare Research and Quality listed the use of a clinical pharmacist to reduce adverse drug events as one of the "Patient safety strategies ready for adoption now" [10]. Pharmacy specialization in critical care carries a practice requirement along with critical care board certification and maintenance. As clinical pharmacists take an

active role in ICUs during multidisciplinary rounds, care has transitioned from a pharmaceutical focus to a patient-centered focus. Emphasis is placed on patient safety and outcomes. As part of the procedural team, pharmacists will typically be consultants in the choice of sedation, pain control, and antibiotic stewardship.

Medicine

Physicians that complete a specialized Fellowship in Critical Care Medicine following their medical education and residency programs join the interdisciplinary team as the primary intensivist or independent consultant. Intensivist management of critically ill patients has been shown to improve mortality and length of stay, and many ICUs now require this specialist input on all patients. Educational preparation in a medical ICU includes 4 years of medical education, 4–5 years of specialized medical education in pulmonary medicine, and a 1–2-year postgraduate fellowship in critical care medicine. Surgical ICU training includes 4 years of medical education, 6 years of surgical residency program, and a 1–2-year postgraduate fellowship in critical care and/or surgery. Upon completion, the physician must pass and maintain board certification.

Historically, residents and fellows provided much of the direct patient care in ICUs of academic institutions. However, as the demand for critical care staff grows, dependence on advanced practice providers as members of the ICU interdisciplinary team is intensified.

Advanced Practice

Physician assistants (PAs) have been present in modern American medical practice for over 50 years. In 1965, Dr. Eugene Stead developed the first recognized PA training program at Duke University with the goal of expediting training of ex-military medics to work in conjunction with physicians in civilian medical facilities. At present, there are 243 accredited PA programs and upward of 131,000 certified PAs nationwide, with a projected growth of 37% from 2016 to 2026. Training for physician assistants takes approximately 24–28 months to complete and consists of classroom and laboratory time followed by an intensive year of clinical rotations. National certification is obtained via national examination with the option for additional specialty training after graduation via residency and fellowship opportunities.

Physician assistants have been integrated into approximately 25% of adult ICUs in academic hospitals across the United States, as well as a variety of nonacademic hospitals. As part of their comprehensive responsibilities, PAs are at the bedside of critically ill patients obtaining medical histories, conducting physical examinations, ordering and interpreting diagnostic and radiologic studies, diagnosing and treating illnesses, prescribing medications, counseling patients and family members on current and preventive healthcare, performing bedside procedures, and assisting in surgical procedures.

As advanced practice providers, nurse practitioners in the ICU often fulfill an identical role to physician assistants. They have prescriptive authority and, in most critical care environments, procedural privileges. Training as the operator in minor procedures such as central and arterial line placement, chest tube insertion, lumbar puncture, and suturing is standard in most acute care nurse practitioner programs. Additional procedural competency can be achieved through postgraduate training with collaborating physicians or as a separate program to obtain certification as a first assist. Nurse practitioners share responsibility with other team members for ensuring the safe preparation and consent along with periprocedural orders and assessment. They work under the supervision of a collaborating physician and, as they develop mastery, can serve as mentors to medical residents and other trainees.

In ICU teams, APPs are often credentialed for the following procedures:

- Placement of central venous catheters
- Placement of arterial monitoring lines
- Placement and removal of chest tubes
- Thoracentesis
- Paracentesis
- Placement of dialysis catheters

- Placement of pulmonary artery monitoring catheter
- Advanced airway management, including emergent cricothyrotomy
- Complex wound management and debridement
- Bronchoscopy
- Surgical first assistant

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2 Process Improvement and Patient Safety

Shaun A. Paulson and Kyle Cunningham

Introduction

It is impossible to discuss procedures in the intensive care unit without discussing the underlying motivations to deliver advanced care in this location. Many procedures traditionally completed in operative theaters or endoscopy suites are now routinely performed at the bedside. While this may pose some additional planning on the part of the practitioner, it also poses potential benefits for the patient and the institution.

Operating room time is expensive and limited in availability at many hospitals. In addition, staff from multiple departments may be impacted. Nursing and respiratory therapy will be needed to transport the patient. Nursing and anesthesia will be needed to provide care during the perioperative period. Surgical technologists are needed to prepare and manage equipment during the case. Following the case, environmental services will be needed to clean the room and prepare for the next case. Often, extubated patients will need to be recovered in the post-anesthesia care unit by additional nursing staff and anesthesiologists. These required resources come at a premium that can quickly tally in the tens of thousands of dollars.

By performing procedures in the intensive care unit, the need for costly operating rooms or endoscopy suites may be eliminated, thereby reducing the number of staff involved which in turn produces a savings to the patient.

Although it may seem to benefit the institution by providing these surgical services through the operating room, it is actually collectively more beneficial to keep procedures in the least expensive location. By eliminating relatively short cases or procedures, potentially longer cases with decreased downtime can be completed. Additionally, it opens up operating room time for elective procedures that would otherwise be forced to competing institutions or, worse yet, leave patients untreated.

The greatest benefits of performing procedures in the intensive care unit remain the direct benefits to the patient. Each time the patient is moved, there is an associated handoff of care, which creates the potential for missed information or communicate lapses. By staying in the unit, the patient is not subject to high-risk transfers when in critical condition which could lead to a more timely and overall improved outcome.

Intensive care unit-based procedures present a two-pronged approach to improving value. Firstly, a better product is delivered by offering the patient a service in their own intensive care unit room. Procedures are performed by team members par-

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ticipating in the daily care of the patient and with comprehensive knowledge of the patient's health conditions. Secondly, costs are reduced by eliminating expensive resources such as specialized staff and facility space. As illustrated in the value equation, the coupling of the aforementioned approaches improves the quality of the service offered as well as the value of the services provided to the patient. Bundled payments and population-based healthcare are growing in popularity and mandate that institutions work to provide an increased value. "A dollar saved is a dollar earned" has never been more true.

So how should this strategy be implemented and procedures brought to the bedside? With the complete buy-in and a tone voiced by institutional leadership, it will take a team comprised of both executives and bedside team members. In this chapter, we will take an in-depth look at what it takes to ensure patient safety through process improvement initiatives such as process improvement (PI) committees, quality assurance (QA), and methodologies.

Process Improvement/Quality Assurance

Hospital Committee Enhancement in Patient Safety

Much of medicine is hands on and performed at the patients' bedside. The hands-on approach and validation of skills are important and necessary for safely performing bedside procedures; however, developing a system for review is just as essential if not more so. Many medical clinicians have turned to examples used in business to help influence systemic change in the medical field. Business create models that are used in the development of strategies with the intent of ensuring the quality of the goods and/or services offered, as well as improving the management of multidisciplinary work [1]. Incorporating the approaches used in the business development of strategies into the practice of medicine has translated into change that is proven to improve clinical process and patient safety at the bedside.

One suggested process for enhancing patient safety is the establishment of a PI committee. Having a committee is important to healthcare today as the focus is placed on improving quality of care, measuring goals, and establishing a reporting system. A PI committee should be comprised of executives as well as various members of the healthcare team including physicians, advanced practice providers (APP), nursing, respiratory therapists, and clinical nurse leaders. The PI committee ideally would meet monthly to discuss process discovery, process optimization, and process implementations as outlined in the following paragraphs.

Once a committee has been developed, additional questions may then arise: where to start, how to select the correct process, and how to measure success out of a PI project? In adapting a business model to the medical model, the attention should be shifted to the three Ps for continuous process improvement: process discovery, process optimization, and process implementation. The three Ps should form the base of any process improvement effort [2]. The following should be considered while defining the foundation for the improvement effort:

1. Which critical processes/problem could be positively impacted by a well-defined and streamlined process?
2. What will the improved process add to the safety of your patients and staff?
3. What will be required to implement the improvement?

Once an understanding of the foundation for the improvement efforts is established, the next step is to create a plan for the process improvement initiative by following the three Ps [2, 3]:

1. Process discovery: Developing a reporting system for the system to anonymously report incidents that the committee is able to review will be the first step in discovery. Next, selecting the project can be an intimidating process in itself. Always keep the bigger picture in mind and think about what process will have the greatest impact.

2. Process optimization: Once the process to be improved is identified, the next step is to think about how to optimize the process, i.e., establishing goals, defining the scope of practice, and development of a subcommittee.
   (a) Setting goals for the process is crucial. The goals need to be measurable. In healthcare, if it cannot be measured, then it cannot be improved [3]. Some common themed goals for healthcare are to reduce and/or eliminate unexplained or inappropriate variation in care, promote multiprofessional education of process improvement initiative, monitor compliance of guidelines, and improve patient care, patient safety, and clinical efficacy through structured process improvement initiatives.
   (b) Define the scope of the project. Develop a clear and concise written statement that relays the purpose of the project.
   (c) Develop a subcommittee to manage the project: The committee should consist of a representative from each discipline that the project involves.
3. Process implementation: Upon completion of discovery and optimization, the next step is the implementation stage. Every member of the team including members who will use the process on a daily basis is involved during implementation. PI does not stop with implementation; it is a continuous process. The final step in the initiation is the development of an evaluation tool for the solution. By doing so, it will help to determine if previously established improvement goals have been met.

With any process improvement initiative, there must be continuous evaluation as perfection cannot be maintained without ongoing monitoring and the implementation of best practices. Once improvements have been implemented into the plan, the process repeats itself with each implementation of approved adjustments.

Now that a process improvement initiative has been developed, it is vital to the success to track quality of care and outcomes by developing a quality assurance program.

Methodologies

Methodologies are often derived from the process improvement initiatives. They are enhancement to ensure patient safety. Some key methodologies that support the structure of enhanced patient care and safety are simulation labs, the "time-out" patient handoff, and evidenced-based protocols/guidelines. In the following section, we will discuss each methodology.

Simulation

The Institute of Medicine (IOM) report titled "To Err is Human" brought attention to the unsettling issue of medical errors, leading to deaths in 1999. It was estimated that each year, 45,000–98,000 patients die in the United States as a result of medical error [4]. As a result of the staggering numbers being reported, the report called for a system change. The Agency for Healthcare Research and Quality (AHRQ) implemented broad and diverse initiatives including funding for simulation research with the understanding that simulation can complement other organizational change methods to facilitate adoption and implementation of best practices and technologies. The research which spanned 11 years evaluated the effectiveness of simulation and demonstrated improved outcomes in patient care [5].

Simulation is defined as a strategy or technique to mirror or amplify real clinical situations with guided experiences in an interactive fashion [6, 7]. Simulation training is an essential part of training for procedures as it serves as a podium which provides a valuable tool in learning to alleviate ethical tensions and resolve practical dilemmas. The goal behind simulation is to deliver realistic scenarios and provide equipment to allow for training until one can master the procedure or skill. There are four main methods of simulation: human patient simulators, task trainers, standardized/simulated patients, and virtual reality [6–8].

1. Human patient simulators are mannequins designed to provide an accurate anatomic rep-

resentation of a patient. They can display physiologic signs and physical cues and can be remotely controlled by an operator through the use of a computer control module or a remote. They allow learners to practice a variety of medical procedures including airway maneuvers, i.e., intubations, bronchoscopy, bag-valve-mask ventilation, needle cricothyroidotomy, forms of vascular access, and life support procedures such as cardioversion and defibrillation.
2. Task trainers are partial body simulators that are used for training in specific tasks and/or procedural skills.
3. Standardized, or simulated, patients are real people who are recruited and trained to portray patients in a reliable and consistent manner.
4. Virtual reality simulators use a computer screen to create simulated patients and patient care environments. The interactions that take place are virtual in that the learner interacts with the patient utilizing a computer interface in an electronically rendered environment, rather than a physical simulator.

The Time-Out

Communication failures have been a long-standing threat to patient safety and are often the most frequently cited cause of adverse events. Strategies have been adapted uniformly to improve communication in both the procedural and nonprocedural settings. In 2003, the Joint Commission elevated the concerns for wrong-site surgery by making its prevention a National Patient Safety Goal and the following year required compliance with a Universal Protocol [9]. The Joint Commission went a step further by not only requiring the site to be marked but a "time-out" (TO) to be performed. A TO requires communication among all team members. It allows members of the team to discuss the plan and any concerns he or she may have [10].

Patient Handoff (GAPS)

Hospitals function 24 h a day, 365 days a year; therefore, no practitioner can feasibly stay in the hospital around the clock. Patients will inevitably be cared for by many different providers during hospitalization. The discontinuity in clinical care can cause errors in the game of "telephone" if information is not passed on correctly. Thus, direct communication via verbal or written handoff tools is essential for patient safety following procedures. The process for which the care of a patient is transferred from one provider to the next is called "handoff." The act of relaying information regarding patients from one provider to the next is called "sign-out" [9].

Following a procedure, a postoperative note documenting the procedure with findings and events is important in communicating to all members of the team. The postoperative period begins at the cessation of a procedure. A system-based approach to postoperative assessment is to be performed to recognize complications early and appropriately act upon. Without accurate documentation and precise sign-out during the handoff process, complication can be missed, leading to a detrimental outcome for the patient.

Protocols

Much of today's medicine has been protocolized. Why, you ask? Patient safety is the number one reason. PI initiatives have identified areas of risk, and through the process and research, best practices have been developed. Protocols are roadmaps that allow practitioners to deliver evidence-based medicine to patients in a safe and effective way.

Just Community Initiatives

It is worth noting that an outcomes-based approach will miss a significant number of structure and process issues. An emerging approach to

process improvement and quality assurance analyzes events independent of outcome. The principles of Just Community maintain that identical events should be scrutinized independent of outcome, separating failures into three categories:

1. Error in judgment
2. At-risk behavior
3. Reckless behavior

Each category will require a different approach. Punishing providers for mistakes impedes process improvement and blurs transparency. The Just Community approach embraces this philosophy and provides a framework for implementation [11].

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The Administrative Process

3

Joseph W. Keller, Teresa D'Alessandro, Elisha F. Yin, Vishal Bakshi, and Christopher D. Newman

Introduction

Credentialing and privileging are fundamental mechanisms employed by healthcare facilities to ensure that only qualified, competent healthcare professionals are granted access to patients and authorized to practice medicine. The administrative steps necessary to ensure that nurse practitioners and physician assistants (referred to hereafter as advanced practice providers (APPs)) are properly credentialed and privileged to practice medicine and perform invasive procedures can appear onerous at first glance. The purpose of this chapter is to digest these requirements into their key elements and equip the APP or administrator with the accepted terminology and knowledge necessary to successfully comply with the requirements of the various regulatory and accrediting bodies.

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The terms privileging and credentialing are often incorrectly interchanged. They are two separate and distinct processes; both of which are key to establishing the qualifications and competency of a medical provider prior to a clinical appointment within a healthcare organization. Credentialing is the formal process of vetting a provider prior to medical practice, while privileging is the formalized process of authorizing a healthcare provider's scope of practice once the credentialing process has been successfully completed. Credentialing consists of collecting, assessing, and verifying all the candidate's qualifications or credentials to determine if the minimum requirements for practice are satisfied. Much of the requisite documentation is standardized by external regulatory agencies, but individual institutions may establish requirements that exceed the minimum standard. It is imperative that the APP and institution are familiar with the requirements specific to their state and practice.

The privileging process is internal and governed by practice administration and medical staff bylaws. The prevailing principle is to establish a competency standard and apply this standard equally to all providers requesting permission to practice at the facility. During the privileging process, documentation of a candidate's competency is again evaluated through the collection, verification, and assessment of supporting documentation. Once completed, the privileging status of all pro-

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viders is to be readily accessible by all hospital staff. This serves as an added safety measure to ensure that healthcare providers practice within their authorized scope of practice.

The chapter concludes with a discussion outlining the key concepts of maintenance of certification (MOC). Certification and licensure can be granted by a state and/or national body depending on the profession. Certification and licensure are typically applied for after successful completion of academic and clinical training and granted upon the successful completion of formal standardized examinations assessing the candidate's competency of medical, ethical, and regulatory knowledge. Certification and licensure are required before initial credentialing and privileging and in most states have a maintenance period of two years with varying criteria based on state and profession. We will discuss the MOC typical to the APP practice with the understanding that the requirements may vary from state to state.

Credentialing

The history of regulatory agencies in the United States dates back to 1917 when the American College of Surgeons (ACS) created a one-page guide titled "Minimum Standard for Hospitals" with the purpose of measuring patient satisfaction. A year later, the ACS looked at 692 hospitals, and a mere 89 of them met the minimum standard. This evolved into the ACS developing the first "Minimum Standard" manual in 1926; a total of 18 pages. In 1951, the American College of Physicians, the American Medical Association, and the Canadian Medical Association joined the ACS to create The Joint Commission on Accreditation of Hospitals. Additionally, the Centers for Medicare and Medicaid Services (CMS) now publishes specific "Conditions of Participation" (CoP) with which healthcare organizations must comply in order to participate in the Medicaid and Medicare programs [1].

Collecting and vetting the qualifications of an APP are required by The Joint Commission. The goals of vetting include patient protection, risk management and avoidance of legal liabilities such as claims of negligence, compliance with regulatory and accrediting agencies, and protecting the reputation of the organization.

In 2007, The Joint Commission (HR.1.20) renewed focus on verifying qualifications of APPs and established the expectation that physician assistants and nurse practitioners must be credentialed through medical staff offices. Standards set by The Joint Commission require that all APPs entering a facility must be vetted by the same body, ensuring equitable opportunity and scope of practice in the same facility.

In addition to The Joint Commission standards, many states require collaborative or supervisory agreements between APPs and physician colleagues. These requirements can vary from PA to NP profession and from state to state. It is important for APPs and hospital administrators to be current and knowledgeable of the established requirements. These requirements can typically be found on the state medical or nursing board website.

Each provider practices under accepted medical staff bylaws approved at the hospital or practice level. These bylaws establish the minimum credentialing criteria and ensure compliance with state and federal regulations of practice. They describe the duties, rules, and regulations, hearing and appeals processes, as well as policies and procedures for all provider practice and allied health caregivers. The hospital is responsible for outlining its credentialing process in its bylaws.

The APP may also be referred to in some hospital systems as an "allied health practitioner" or AHP, meaning an individual other than a physician (excluding dentist, oral and maxillofacial surgeon, podiatrist, or psychologist) who is qualified by academic and clinical training and by prior and continuing experience and current competence in a discipline which the AHP Review Committee has determined to allow to practice in the hospital" [2].

The Joint Commission standards require the hospital to obtain primary verification in writing the qualifications of skills and clinical knowledge. Primary sources may include the certifying boards, letters from professional schools, and let-

ters from specific training programs. When reviewing the information presented for credentialing, the medical staff office will ensure that the current or previous licenses or certifications have never been challenged or in question. Further evaluation will be made in the event of voluntary or involuntary relinquishment of licenses or certifications. These efforts evaluate for current liability or patterns suggesting an increased risk of future liability.

Insurance is usually covered by a supervising or collaborative physician to the APP. Requisites are the APP's name, limits of liability, and effective dates with expiration. Hospitals should automatically suspend APPs who do not provide proof of current coverage.

Once the medical staff office has collected and vetted all of the required qualifications, they then must present the information in its entirety to a committee, specific to the credentialing and privileging of the APP. The four steps to final approval are department chair's review, credentialing committee's review, medical executive committee's review, and governing board's review and final decision. In the event of an unfavorable decision among the credentials committee and board, the medical staff office will want to consult with their legal counsel to discuss the appropriate steps to accommodate proper legal requirements. Denial of privileges entitles the APP the rights to a hearing.

An APP applying for privileging and credentialing to a hospital has the responsibility of providing all documentation to fulfill the criteria requested. The medical staff office may close the request for credentialing if the information has not been presented in completion. If this occurs, the hospital would then send a letter to the applicant explaining the discontinuance of the process.

Privileging

Although the terms credentialing and privileging are often used together and sometimes interchangeably, they are two distinct processes. The Joint Commission defines privileging as "the process whereby a specific scope and content of patient care services (i.e., clinical privileges) are authorized for a healthcare practitioner by a healthcare organization, based on an evaluation of the individual's credentials and performance." A "privilege" is defined as an advantage, right, or benefit that is not available to everyone; the rights and advantages enjoyed by a relatively small group of people, usually as a result [3] of education and experience." Privileges are usually granted by an institutional medical staff committee.

Privileges can be further separated into "bundled/core" or "special" privileges. The core privileges represent the everyday activities that a competent APP should be able to perform based on their general education and training, such as history taking, performing physical exams, and interpreting laboratory tests. Special privileges are for procedures that are either performed infrequently, carry greater risk of complications, or both. For APPs, this category usually includes procedures that are learned on the job as opposed to in school. As this is a textbook for interventional critical care, many of the procedures addressed in this text will fall into the "special" category, requiring separate privileging. One might assume that the definition of "core" and "special" is standardized across institutions, but studies have found wide disparity between what individual institutions consider core or special [4]. It is the responsibility of the APP to know which procedures his or her institution considers "special" and to apply for those specific procedural privileges as appropriate.

Privileging takes place at three distinct times: during initial application to the medical staff of a healthcare institution, during routine re-credentialing/re-privileging process (typically every two years), and when an APP wishes to request new privileges or a set of core privileges. There are many resources that address processes for requesting initial core privileges and core re-privileging. As this is a procedural text, the focus here will be on special procedure privileging.

Institutions are free to set their own standards for initial privileging for special procedures. However, most institutions will request either an activity record demonstrating sufficient practice in the requested procedure, an attestation from a

competent supervisor or preceptor stating the applicant's competency in the requested procedure, or both. No standard exists as to how many procedures are satisfactory, but many institutions set a bar at three to five in the prior two years.

Once a privilege for a special procedure is granted, the APP will need to re-privilege, typically every two years. For many years, most institutions considered a log or other proof of activity sufficient for re-privileging. But emerging evidence suggests that such logs may not be sufficient to demonstrate competence, proficiency, or breadth of experience [5]. In short, performing a procedure often, but poorly, is not an adequate demonstration of skill. Therefore, some institutions are migrating away from re-privileging based purely on volume and are incorporating additional objective evaluations of proficiency. This may take the form of a peer evaluation, review of outcomes, or evaluation in a simulation/under direct observation.

The other opportunity for requesting special procedure privileges is when the APP is learning a new procedure. In the current regulatory environment, the old adage of "see one, do one, teach one" is no longer sufficient. A dilemma exists, however: the institution will not allow an APP without a privilege for a procedure to perform the procedure, but the APP cannot gain the privilege without demonstrating proficiency at the procedure. To resolve this dilemma, many institutions have developed specific requirements to obtain new procedure privileges. These may begin with a formal didactic curriculum and then may move on to incorporate simulation and observation of the procedure. There is evidence that simulation can enhance skill and confidence with new procedures and should be utilized whenever available [6].

At some point, the APP must be able to demonstrate proficiency in the procedure with an actual patient. There are two components to this. Precepting involves a clinician with proficiency in the procedure teaching the APP how to perform it. The preceptor has an existing relationship with the patient, is responsible for the outcome, will document the procedure, and will submit any billing. Once the APP has learned the procedure, he or she can then be proctored. A proctor is a neutral clinician who holds the privilege being demonstrated, does not have an existing relationship with the patient, and does not assume responsibility for the patient outcome. In this circumstance, the APP documents the procedure (acknowledging the presence of the proctor) and submits any billing. The proctor records his or her observations, which are then submitted with the privileging request. This proctoring relationship requires a formal plan that outlines what is to be proctored, what criteria will be used for evaluation, and how/to whom the final assessment will be submitted. Once the APP has met the conditions specified in the proctoring agreement, the APP may then submit a request for privileges in the new procedure through the medical staff.

APPs are subject to state and federal rules that may restrict what procedures are performed and in what circumstances. Advanced practice registered nurses and physician assistants may have different privileging requirements, and procedures may be considered "core" for one group and "special" for another. Therefore, it is the responsibility of the APP to ensure he or she is appropriately privileged before performing any procedure.

Maintenance of Certification

Maintenance of certification (MOC) provides an expectation that the APP will engage in certain activities to maintain clinical competency allowing governing bodies and hospital systems to verify the status of their APPs.

In some circumstances, APPs may be required to retest on a cycle to maintain certification. For example, both physician assistants (PAs) and advanced practice registered nurses (APRNs) must pass an initial credentialing examination after completion of their respective training programs. Licensure is then maintained every two years with proof of continued medial education.

Every two years, APPs are expected to complete continuing education credits and submit these to their governing bodies, the National Commission on Certification of Physician Assistants (NCCPA) for PAs and the American Academy of Nurse Practitioners for APRNs. This demonstrates a commitment to clinical competency and performance improvement. These credits may be gained in person by attending conferences and seminars, or through forms of media, such as medical journals and online subscriptions. If required, the APP will submit a post-test evaluation to the sponsoring institution or organization, which allows for verification of credits earned [7].

Many if not most organizations now provide a yearly stipend to support at least a portion if not all of the financial costs associated with continued education and provide their APPs business and/or meeting days which allows for professional development and learning engagement. New graduates or new applicants should consider asking questions related to educational and licensure reimbursement upon applying and interviewing for a position.

In order to meet The Joint Commission standards, hospitals and practices must have implemented processes which comply with regulations for MOC. The APP will have to verify several integral items, including updating whether or not he or she has been involved in litigation and has professional liability claims and if boards were recertified successfully [8, 9]. The Joint Commission requires an Ongoing Professional Practice Evaluation (OPPE), which is a "document of ongoing data collected for the purpose of assessing a practitioner's clinical competence and professional behavior. The information gathered during this process is factored into decisions to maintain, revise, or revoke existing privilege(s) prior to or at the end of the two year license and privilege renewal cycle." "The OPPE requirements apply to all practitioners granted privileges via the medical staff processes, including allied health practitioners, such as Physician Assistants, Advanced Practice Nurses, etc. OPPE allows organizations to identify professional practice trends that impact the quality and safety of patient care. It is the responsibility of the organization's medical staff to determine the criteria used in the ongoing professional practice evaluation" [10].

Additionally, as APPs collaborate with physician colleagues, it is imperative that opportunities for feedback are provided. Some institutions address this need by implementing a system for formal quality monitoring typically administered biannually at a minimum. The completion and satisfactory result of the quality monitoring is requisite to the APP's MOC at his or her hospital or practice [11].

All APPs must be cognizant of their requirements for MOC at both the local and national level. It is the responsibility of the individual to complete and submit the necessary requirements. It is recommended that APPs maintain accurate records of their documentation, including license verification of continuing medical education credits in the event of an audit or to satisfy the MOC processes.

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Coding and Billing for Procedures

4

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Introduction

Coding and billing for procedures performed are an important part of the service delivered by the advanced practice provider. Assuring that the proper documentation of the service and providing the appropriate code allows the procedure to be reimbursed at the appropriate rate and in an efficient manner. Understanding the regional reimbursement rules, policies, and procedures allows for the APP to have impact on the value to the practice. Billing and coding for procedures may require complex descriptors and additional documentation depending on the procedure performed. Billing and coding incorrectly or inappropriately may lead to delays in reimbursement, denials, as well as potential issues of waste, abuse, and fraud. Significant penalties may be levied by CMS for incorrect and inappropriate billing to the provider. A good basic understanding of these concepts will help guide the provider to providing the right code and appropriate reimbursement.

Performing procedures is part of the skill set of APPs in practice and is a common part of many providers' role in the care complex patients such as those in the emergency department, the intensive care unit, and the operating room. Regulations surrounding individual procedural credentialing that relates to individual hospital policy and bylaws as well as local or state regulations on procedures are beyond the scope of this chapter. Private insurance companies also may require different documentation and have different policies related to processing APP billing for procedures. Knowledge of regulations and rules that apply to your local practice is critical.

APP Billing and Coding

APPs provide professional services that are reimbursed through Medicare Part B. APPs do not provide the types of service covered under Medicare Part A, so the salaries of hospital-employed NPs and PAs should not be reported in the Part A cost report. Administrative functions, not clinical duties, may be an exception to this rule.

Medicare regulations covering physician assistant billing are found under the Medicare Benefit Policy Manual, Chap. 15, Section 190, and regulations covering nurse practitioners are found in Section 200. State law and hospital regulations further guide practice and performance of procedures for the APP [1].

Under Medicare's rule, procedural services provided must be billed under the NPI of the indi-

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vidual that performed the procedure. If an APP performs the procedure, it should be properly documented and billed under that provider. There may be exceptions to this policy, such as when the APP is in the initial credentialing process and being proctored by a supervising physician. Check with your local Medicare carrier if this may apply to your local program.

Coding Modifiers

Modifiers are additions to a CPT code that allows for efficient processing and payment. They are generally two numbers or letters that are added to the CPT code to give additional context or to describe additional actions. Some procedures require modifiers. Lack of appropriate modifiers, absent modifiers, or modifiers that do not reflect the service could result in delay in payment or denials (Table 4.1).

An example of the appropriate use of a modifier would involve bilateral chest tubes. This would be coded as CPT 32551-50. The -50 modifier would make it evident that there are two separate procedures (left and right chest tubes). Submitting two separate CPT 32551 would possibly lead to denial as it would be a duplicative procedure.

Procedural Codes

The following covers some of the more common procedural CPT codes and general applicability of those codes. Chapters in this book also contain applicable CPT codes for individual procedures listed. This is not meant to be an exhaustive list but a starting point for understanding the codes. When using image guidance such as ultrasound, it should be mentioned in the documentation, and images should be captured and retained with patient information.

Table 4.1 Examples of modifiers

Modifier – 25: Significant, separately identifiable evaluation and management service by the same physician, or other qualified healthcare professional on the same day as the procedure or other service
Modifier – 50: Bilateral procedure
Modifier – 62: Two surgeons (providers)
Modifier – 82: Assistant surgeon (when qualified resident surgeon not available)
Modifier – AS: Physician assistant, nurse practitioner, or clinical nurse specialist services for assistant at surgery

Table 4.2 Codes bundled into Critical Care Codes (CPT 99291 – 99292)

Interpretation of cardiac output measurements: CPT 93561, 93562
Chest x-rays, professional component: CPT 71010, 71015, 71020
Blood draw for specimen: CPT 36415
Blood gases and information data stored in computers: CPT 99090
Gastric intubation: CPT 43752, 91105
Pulse oximetry: CPT 94760, 94761, 94762
Temporary transcutaneous pacing: CPT 92953
Ventilator management: CPT 94002 – 94004, 94660, 94662
Vascular access procedures: CPT 36000, 36410, 36415, 36591, 36600

There are some procedural codes that are not permitted to be billed separately when critical care codes are billed (CPT 99291-99292). See Table 4.2 for the list of excluded codes [2]. If not performing critical care billing, such as other E/M codes, these codes may be billed separately. Patient age may be a factor in some codes such as ECMO services and central lines.

Arterial Access Procedures

- Arterial line: CPT 36620
- Arterial line with cutdown: CPT 36625

Airway Procedures

- Emergent intubation: CPT 31500
- Emergent tracheostomy: CPT 31603
- Tracheostomy: CPT 31600
- Tracheostomy changes: CPT 31502
- Therapeutic bronchoscopy: CPT 31622
- Therapeutic bronchoscopy with lavage: CPT 31624

Chest Procedures

- Tube thoracostomy (cutdown, blunt or sharp dissection): CPT 31551
- Thoracentesis, aspiration of pleural space: CPT 32554
- Thoracentesis with image guidance: CPT 32555
- Percutaneous placement of pleural drains: CPT 32556
- Percutaneous placement of pleural drains with imaging guidance: CPT 32557

Abdominal Procedures

- Paracentesis without image guidance: CPT 49082
- Paracentesis with image guidance: CPT 49083

Vascular Access

- Insertion of non-tunneled centrally inserted central venous catheter <5 years of age: CPT 36556
- Insertion of non-tunneled centrally inserted central venous catheter >5 years of age: CPT 36557

Ultrasound or Fluoroscopy Guidance for Vascular Access: Add-On Code

- These codes must be associated with an associated procedure code (e.g., central line code)
- Fluoroscopy guidance central venous device: CPT 77001
- Ultrasound guidance central venous device: CPT 76937

Wound Vac Application/Changes

- Negative-pressure wound therapy for wounds < or = 50 square cm: CPT 67605
- Negative-pressure wound therapy for wounds >50 square cm: CPT 67606

Neurologic Procedures

- Lumbar puncture, diagnostic: CPT 62270
- Lumbar puncture, therapeutic (including drain): CPT 62272

Billing and Coding for Operative Assisting

APPs may provide surgical assistance in settings where physician residents also provide care; this is often referred to as teaching settings. APPs may also provide operative surgical assistants in nonteaching settings. The role of the APP as a surgical assist may also occur in the emergency department and increasingly in the intensive care unit.

In relation to the coders, the modifier -AS (assistant) should be listed to each operative procedure code. Proper documentation included in the operative report should be clear regarding how the APP assistant participated in the procedure.

Medicare has determined and maintains a list of approximately 1900 surgeries (~5% of all surgeries) that permit first assistant billing, and this is found in the Medicare Physician Fee Schedule Database. Medicare reimbursement for the APP for surgical assisting services is 85% of the physician surgical assist fee, when appropriate. The physician surgical assist fee is 16% of the surgical fee. Medicare applies the discount with the noted modifiers. The final reimbursement when the discount is applied for the APP would amount to 13.6% of the surgical fee. Reimbursement in nonteaching/nonacademic centers is generally straightforward. If operative assist occurs within an academic or in teaching hospitals, more criteria must be met [3]. It is important to follow appropriate guidelines to ensure appropriate reimbursement for APP surgical assisting in this setting. Payment in those circumstances is made when any of the following criteria are met and documented:

1. *The surgeon has a policy of never involving residents in the care of his or her patients*

   This is generally the case with community surgical practices that do not use residents or provide surgical training but there may be unique cases within other hospital settings.
2. *A qualified resident is not available*

   The exact criterion for what constitutes a qualified resident is vague and may be left to the primary surgeon's discretion. However,

the general view is that if there is training program related to the surgical procedure being performed and a qualified resident is available, reimbursement is not provided to the APP. In some instances, a qualified resident might not be available. Examples of unavailability may include resident involved in educational activities, off duty, or participating in another surgery. The degree of surgical complexity may also factor into the determination of what constitutes a qualified resident.

3. *Exceptional circumstances*

   Multisystem trauma and other life-threatening cases such as emergent surgery may require additional or even multiple assistants in surgery. In these cases, reimbursement for the APP or an additional surgeon or surgeon may be appropriate. These exceptional circumstances should be well documented to justify reimbursement even when other qualified residents are available.

For processing appropriate claims in academic or teaching hospitals, additional documentation and certification is required. The modifier -82 should be added to the code in a case in which a qualified resident surgeon was not available. The following is an example of proper documentation that may need to be provided and attested to:

> I understand that §1842(b) (7)(D) of the Act generally prohibits Medicare physician fee schedule payment for the services of assistants at surgery in teaching hospitals when qualified residents are available to furnish such services. I certify that the services for which payment is claimed were medically necessary and that no qualified resident was available to perform the services. I further understand that these services are subject to post payment review.

Fraud, Waste, and Abuse

Providers submitting claims to Medicare and Medicaid services become responsible for all applicable rules and regulations for these organizations. A comprehensive onboarding process of APPs should include education on billing and coding as well as an understanding of compliance issues and risk. Practices should screen providers for exclusion from these programs and review compliance plans on at least a yearly basis to review expectations of conduct and to understand the implications of improper conduct [4].

Fraud, waste, and abuse are considerable threats to CMS, and the US government has a significant interest in mitigating losses to the taxpayer. Best estimates on the true cost of fraud and abuse are ~3–10% of the federal plan or approximately $20–60 billion annually. Because of this, the government has a number of measures to recoup losses and to hold both individuals and institutions accountable for inappropriate claims or fraud. The government has a variety of enforcement and recovery programs and also promotes self-reporting when errors do occur. Some examples of federal law that apply to fraud and abuse include the False Claims Act, Anti-Kickback Statute, Social Security Act, Physician Self-Referral Law (also known as the Stark Law) and US Criminal Code [5].

There have been many areas of improvement within government agencies/contractors that have helped to focus on areas of abuse and fraud. Decision support software, risk/exposure analysis, and sophisticated data analysis and algorithms have helped to identify areas for potential for abuse, fraud, and billing inaccuracies. Each year, the Office of Inspector General of the US Department of Health and Human Services develops work plans that focus on areas of concern for waste and abuse potentials. CMS has also developed Recovery Audit Programs that review claims and work to recover overpayments for services billed [6]. Another tool that benefits the US government is whistleblower or qui tam claims and provisions. Individuals that submit claims may be eligible for potentially collecting up to 25–30% of settlements [7].

Fraud is the knowingly billing for services not furnished. It includes falsifying records and billing Medicare for services not provided [5]. Other examples may include knowingly billing for services at a higher level than provided or docu-

mented (site). Abuse is a practice that results in unnecessary costs and may include practices that are not consistent with medical necessity. Examples include misusing codes on a claim, upcoding, unbundling, and providing unnecessary procedures.

Abuse is defined as a practice that results in unnecessary cost. This includes practices that are not medically necessary and that meet recognized standards of care [5]. Example would be billing for services that are not medically necessary, excessive charges for services, and misusing codes on a claim – upcoding and/or unbundling codes.

Fraud and abuse practices expose the provider and practice to criminal and civil liabilities. This may include imprisonment, fines, exclusion from participation in Medicare and Medicaid programs, as well as loss of professional license.

Keys to Success, Perils, and Pitfalls

- Document appropriately for services performed in a concise manner.
- For first and/or second assist in surgical procedures, make sure your role in the operation is documented.
- Review compliance guidelines and policies on a yearly basis.

Summary

Billing and coding are an important part of the overall procedure. A comprehensive understanding of the issues surrounding billing and coding will help improve the value that the APP brings to the practice and helps to prevent issues with compliance to regulations and rules. Vigilance in keeping up to date on the ever-changing landscape of coding regulations and compliance issues is also important.

Disclaimer This chapter does not represent any legal advice and was based on current understanding of CMS rules and regulations at the time of its writing. Ultimately, the accuracy and responsibility of the claim submission rest with the provider of the service.

References

1. Centers for Medicare and Medicaid Services: https://www.cms.gov/Regulations-and-Guidance/Guidance/Manuals/downloads/bp102c15.pdf. Accessed 6 June 2020.
2. Centers for Medicare and Medicaid Services: https://www.cms.gov/Regulations-and-Guidance/Guidance/Transmittals/downloads/R2997CP.pdf. Accessed 6 June 2020.
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4. Health and Human Services, Office of the Inspector General: http://oig.hhs.gov/compliance/provider-compliance-training/files/Compliance101tips508.pdf. Accessed 6 June 2020.
5. Centers for Medicare and Medicaid Services: https://www.cms.gov/Outreach-and-Education/Medicare-Learning-Network-MLN/MLNProducts/Downloads/Fraud-Abuse-MLN4649244.pdf. Accessed 6 June 2020.
6. Centers for Medicare and Medicaid Services: https://www.cms.gov/research-statistics-data-and-systems/monitoring-programs/medicare-ffs-compliance-programs/recovery-audit-program/. Accessed 6 June 2020.
7. Centers for Medicare and Medicaid Services: https://downloads.cms.gov/cmsgov/archived-downloads/SMDL/downloads/SMD032207Att2.pdf. Accessed 6 June 2020.

Additional Resources

Centers for Medicare and Medicaid.: https://www.cms.gov

American Association of Physician Assistants: https://www.aapa.org/advocacy-central/reimbursement/

American Academy of Professional Coders.: https://www.aapc.com

Part II

Airway Procedures

Airway Management in the ICU

5

Brian E. Lauer, Cynthia W. Lauer, and Ronald F. Sing

Indications

The first step of interventional airway management is to determine the indication for tracheal intubation. There are multiple indications for interventional airway management to include cardiopulmonary arrest, pending respiratory failure requiring mechanical ventilation, need to minimize the work of breathing (e.g., septic or cardiogenic shock), altered mental status and airway protection, pending airway obstruction from trauma, bleeding or infection, or facilitating a procedure (e.g., cardioversion or bronchoscopy). The indication for the intervention often will determine the equipment used and the pharmacological agents the provider will choose. If the provider understands the indication for airway management, another course of action may be available to avoid an airway intervention. For example, a patient arrives from the operating room and is demonstrating respiratory depression and hypercarbia. The provider is called to the bedside for airway intervention. In determining the cause of pending respiratory failure, the provider may realize that the patient may have opioid-induced respiratory depression or residual neuromuscular blockade. Prior to intervention, it may be deemed appropriate to provide reversal for each of these causes prior to moving forward. One of the keys of success is often to avoiding interventional airway management if other courses of actions are available.

Preparation

Preparation and familiarity are key components to successful interventional airway management. It is imperative to review the ICUs' standard operating procedures for airway management and review the emergency airway management cart/bag, the capabilities of those personnel involved or whether others are consulted, and which pharmacological agents are available. Key questions every provider should have an answer to prior to interventional airway management are as follows:

- Which personnel are required to attend endotracheal intubations and which are only available by consult (i.e., anesthesia, surgeon of the day, respiratory therapy)? If only available by consult, what is their typical response time?
- What are the capabilities of those involved? Respiratory therapists have different credentials depending on state governing bodies and healthcare institutions. Who administers the

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medications? Is there a standard medication list with standard dosing? Is the same provider responsible for ordering medications and airway management? Is the provider able to easily acquire different medications if the situation dictates?
- What equipment is available for interventional airway management? Does the ICU have its own video laryngoscope or does it need to come with the anesthesia service? Does the airway cart have a variety of airway adjuncts such as laryngeal mask airways (LMAs), intubating stylets (bougie), oral and nasal pharyngeal airways, and direct laryngoscopy blades? Is there a cricothyroidotomy kit available if needed?

All these questions should be addressed and possibly optimized prior to the first patient requiring airway management.

Assessment

History

Medical, surgical, or anesthetic factors may be indicative of a difficult airway. If you are the provider caring for the patient, you will have an understanding of the patient's airway concerns. If you are not, key points of information are diagnosis, chronicity of underlying disorder, allergies, comorbidities, allergies, last intake, and prior difficulties with anesthesia or airway management. Specific history focused on airway-comprising conditions is mandatory. These conditions can be congenital (Down's syndrome, Pierre Robin syndrome) or acquired (Ludwig's angina, supraglottis). Airway difficulties may be due to arthritis (rheumatoid or ankylosing spondylitis), airway tumors, obesity, acromegaly, or acute airway burns. In many of these cases, it is imperative to consult airway experts and be prepared to perform a surgical airway if not successful.

Important areas to note are the mode and oxygen concentration the patient is receiving. Is there an opportunity to improve oxygenation prior to airway management (i.e., increase oxygen concentration, place patient on continuous positive airway pressure, positioning)?

If the provider plans to use succinylcholine for muscle relaxation, knowledge of patient's potassium level, paraplegia, cerebral vascular accidents with residual deficits, burns or crush injuries, ICU days with prolonged immobility, genetic neuropathies, and any history of malignant hyperthermia is mandatory to prevent acute hyperkalemia.

If the provider works in a surgical ICU, it is important to be able to access an anesthesia record for your institution. The airway section will provide details of ease of mask ventilation, intubation difficulty, and type of laryngoscopy blade used.

History gathering should take less than 2 minutes, and during that time, the provider can begin to assess the patient's physical status.

Physical Assessment

Interventional airway management in the ICU setting is difficult. Even if the patient's anatomy, physiology, and comorbidities are favorable for ease of hand ventilation or intubation, the logistics of obtaining equipment, performing the procedure as rapidly as possible on an ICU bed, and using personnel that may have multiple critically ill patients requiring their attention all make interventional airway management in the ICU difficult. Taking even a few moments to optimize positioning, preoxygenating, and denitrogenating and to assign roles prior to induction/laryngoscopy will increase your chance of success.

There are two physical assessments of interventional airway management that should be completed for ease or difficulty: bag valve mask ventilation and tracheal intubation. Often these assessments may overlap. The provider may have a difficult bag valve mask ventilation but an uncomplicated intubation, or vice versa. For instance, edentulism provides for difficult ventilation but suggest less difficulty with tracheal intubation. This is important if the provider cannot intubate the patient. If the provider has the ability to bag valve mask ventilate the patient, it

allows time to develop a new course of action with adjuncts or allow the induction and muscle relaxant to resolve and wake up the patient.

Bag Valve Mask Ventilation

There are many predictors of difficult bag valve mask ventilation to include edentulism, presence of a beard, history of snoring or obstructive sleep apnea, age greater than 55, obesity, neck circumference of 40 cm or higher, or presence of a cervical collar. If a patient has two of the independent factors, there is a high likelihood of difficult bag valve mask ventilation. If the provider determines difficulty, it is important to have ventilation adjuncts (i.e., oral/nasal airways, LMAs) and to designate personnel to assist during ventilation (one person maintaining mask seal and another person compressing the Ambu bag). The provider can also place an LMA to ventilate and remove prior to direct laryngoscopy [1].

Tracheal Intubation

Many airway assessment tools have been developed for providers to determine ease of or difficult tracheal intubation. Tools such as Mallampati score, thyromental distance, mouth opening, and upper lip bite test have been demonstrated to be specific but not sensitive. Many of these predictors require active patient participation. The ICU patient is often in respiratory distress, tachypneic, obtunded, or in a cervical collar and may not be able to participate in the exam. Therefore, it has to be a combination of multiple tests. It must be recognized, however, that some patients with a difficult airway will remain undetected despite the most careful preoperative airway evaluation. Thus, the provider must be prepared with a variety of plans for airway management in the event of an unanticipated difficult airway.

The LEMON airway assessment method encompasses multiple airway exams in an easy to remember mnemonic. The score with a maximum of 10 points is calculated by assigning 1 point for each of the following LEMON criteria:

L – Look externally (facial trauma; bleeding; hematoma; large tongue; large incisors; short, thick neck; micrognathia; obesity; presence of a cervical collar).

E – Evaluate the 3–3-2 rule (incisor distance, 3 fingerbreadths; hyoid-mental distance, 3 fingerbreadths; thyroid to mouth distance, 2 fingerbreadths.

M – Mallampati (no vocalization Mallampati score _ > 3).

O – Obstruction (presence of any condition, especially those of the upper airway like epiglottis, peritonsillar abscess, oral tumor). Prior tracheostomy scar may indicate tracheal stenosis and may require a smaller endotracheal tube.

N – Neck mobility (limited neck mobility either externally (cervical collar) or internally (fusion, arthritis).

Patients in the difficult intubation group have higher LEMON scores [2] (Fig. 5.1a–c).

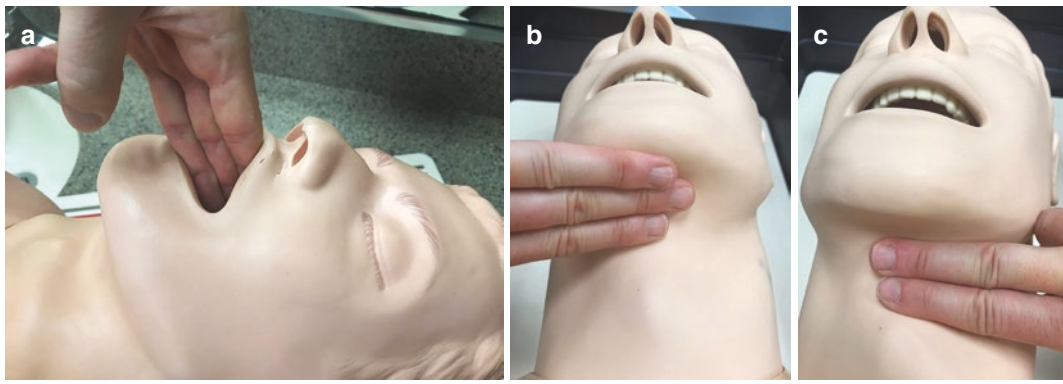
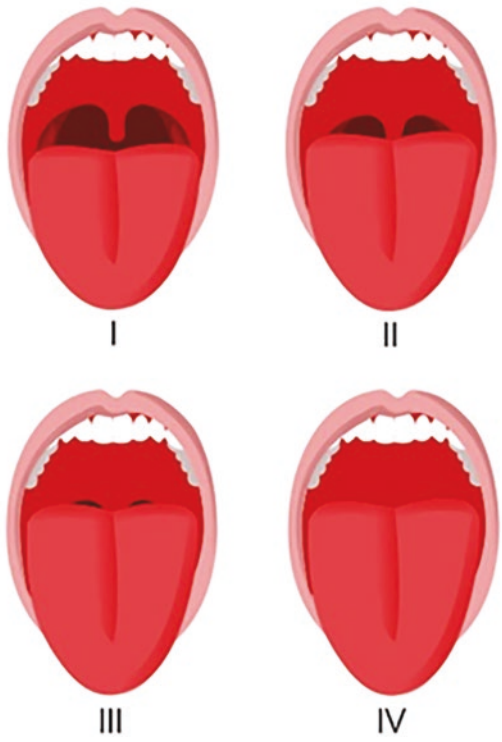


Fig. 5.1 (**a**) Mouth opening, (**b**) hyomental distance, (**c**) thyromental distance



Mallampati score. North Seattle University. Seattle. Cited April 24, 2015. Retrieved from public domain images at: https://facweb.northseattle.edu/cduren/North%20Seattle%20AT%20Program%202011-2012%20CJ%20Duren-Instructor/ATEC%20002%20Anesthesia%20Related%20Anatomy%20and%20Physiology/Week%203/Additional%20Week%203%20Lesson%20Resources/Mallampati%20Score-Mallampati%20Classification%20Picture.png

Quick Airway Assessment

1. Can the patient open the mouth widely to at least 3 fingerbreadths (indicative of temporomandibular joint movement. Indicates if the ability to maneuver laryngoscope)?
2. Can the patient maximally protrude the tongue (inspects the posterior aspect of the mouth/pharyngeal structures)?
3. Patients' ability to move jaw forward. (The upper lip bite test. ULBT is performed by asking the patient to bite his or her upper lip. The test is scored as a class I if the lower teeth can bite the upper lip above the vermillion border, class II below the border, and class III if the upper lip cannot be bitten.) [3]
4. Can the patient fully bend/extend the head and move it sideward?

As described above, like any diagnostic test, an ideal method of airway assessment should have high sensitivity and specificity. No single test of score for airway assessment meets these requirements. If a patient has multiple characteristics as described above, the provider should anticipate and be prepared for a difficult airway.

Pharmacology of Interventional Airway Management

There are three categories of pharmacological agents to be considered to perform tracheal intubation. In some cases, all three categories can be required and in others only one. It is also important to note that medications are documented in a range. Most often due to the patients critically ill nature and multiple comorbidities, the lower range of medications are all that is required. The three categories of pharmacological agents are those that attenuate the response to laryngoscopy (pretreatment), induction of amnesia/unconsciousness, and paralytic agents to facilitate tracheal intubation.

Pretreatment Medications

The decision to use these is generally made by the person directing the intubation process. If being supervised for this procedure, check with the clinician responsible for the procedure and verify if they choose to use one of these medications.

These medications attenuate the cardiovascular response of tachycardia and hypertension associated with direct laryngoscopy. If the patient is critically ill and experiencing hypotension or on vasopressor support, these medications are often not required. The cardiovascular results of direct laryngoscopy may offset the effects of the induction agent in these patients. .

The mnemonic *LOADE* may be used when considering pretreatment medications:

- Lidocaine dose, 1.5 mg/kg IVP (at least 2 min before the intubation procedure).
- Opioid fentanyl, 0.5–1 mcg/kg IV (given slowly over 1–2 min).
- Atropine may be needed if the patient develops non-hypoxemic bradycardia; dose, 0.5–1.0 mg IV; may be repeated if needed.
- Defasciculating dose of a non-depolarizer neuromuscular paralytic if succinylcholine is used.
- Esmolol, 1–1.5 mg/kg (at least 2 min prior to direct laryngoscopy. Short half-life).

Sedation/Induction Medications

Common induction medications used include:

- Etomidate – 0.1–0.3 mg/kg IV, best hemodynamic profile, short acting, risk of adrenal insufficiency
- Versed – 0.1 mg/kg IV
- Ketamine – 1–2 mg/kg IV, used in patients with asthma, provides cardiovascular stability
- Propofol – 1–2 mg/kg IV, monitor for hypotension

Paralytics

Muscle relaxants (paralytics) are often not required in the critically ill/frail patient. In these patients, the induction agent alone is enough to facilitate tracheal intubation. If the provider deems the patient to be a difficult intubation, a paralytic agent in addition to induction agent will provide the best chance of success.

There are two classes of muscle relaxants based on the interaction at the neuromuscular junction:

- Depolarizing muscle relaxants act as acetylcholine (Ach) receptor agonist.
- They bind to the neuromuscular junction and cause an action potential demonstrated by fasciculations. The only commercially available depolarizing muscle relaxant is succinylcholine.
- Non-depolarizing muscle relaxants act as Ach receptor competitive antagonists.
- Binding to the Ach receptor does not allow Ach to bind and cause an end-plate potential. Rocuronium and vecuronium are the most commonly used in the ICU setting. Cisatracurium is the neuromuscular relaxant of choice in renal failure.

Depolarizing Muscle Paralytics

Succinylcholine is actually two-acetylcholine molecules linked together. It has a rapid onset (30–60 s) and relatively short half-life (3–5 min). It is metabolized by the enzyme acetylcholinesterase. There are some populations that have an acetylcholinesterase deficiency. In those cases, the effects of succinylcholine may last longer. The primary advantage of using succinylcholine is that if you are unable to secure the airway, with its short half-life, the medication will be metabolized, and the patient should resume spontaneous respirations within 3–5 min.

The dose of succinylcholine is 1.5 mg/kg. The dose is never reduced. It has no effect on hemodynamics.

There are multiple contraindications to using succinylcholine. They include:

- History of malignant hyperthermia
- Burns >5 days – until healed
- Crush injury to large muscle mass > 5 days
- Spinal cord injury/stroke with hemi- or paraplegia >5 days to 6 months
- Neuromuscular disease
- History of hyperkalemia/dialysis patients
- Prolonged immobility

Non-depolarizing Paralytics

There are many choices. Two will be covered here. Rocuronium is the non-depolarizing muscle relaxant of choice. Due to the multiple contraindications of succinylcholine and the advent of the immediate non-depolarizer reversal agent, sugammadex, most providers are moving away from the use of succinylcholine. Rocuronium provides similar intubating conditions as succinylcholine at the RSI dose. It has an onset of 60 s and a half-life of 30–45 min. It is given at a dose of 1.2 mg/kg IV push after the administration of an appropriate induction.

The second non-depolarizing agent that may be given is vecuronium. It has an onset of 3 min and a half-life of 60–75 min. The intubation dose of vecuronium is 0.15 mg/kg IV push after the administration of an appropriate induction agent.

Determine if sugammadex is available at your institution. If the provider is in a "cannot ventilate/cannot intubate situation" after using the 1.2 mg/kg dose of rocuronium, the sugammadex reversal dose is given 3 minutes after rocuronium at the dose of 16 mg/kg.

The Rapid Sequence Intubation (RSI) Procedure

The RSI procedure was designed to limit the amount of time from the induction of unconsciousness/sedation to securing the airway. It is used to protect the unsecured airway from aspiration of the full stomach. If the patient does not have a full stomach, it is appropriate to hand ventilate the patient prior to laryngoscopy. It will allow the provider to oxygenate more effectively giving the laryngoscopist more time to secure the airway. In addition, if the provider can easily provide effective hand ventilation and then encounters a difficult intubation, the provider can hand ventilate while additional support can be called.

The RSI procedure has been described as the seven "Ps" [4]. They are:

- *P*reparation
  - Monitors (ECG, SpO_2, $EtCO_2$, BP), reliable IV access, equipment, video laryngoscopy, suction. Assign roles. Prepare ICU bed.
- *P*reoxygenation
  - 3 min of 100% FiO_2 (or 8 vital capacity breaths). If the patient is not following commands, provide pressure support breaths with an Ambu bag. Taking even a few moments to optimize positioning and preoxygenate/denitrogenate may provide you the crucial seconds needed to differentiate a successful intubation from a desaturation and an emergency.
- *P*ositioning
  - Sniffing position. It is not uncommon to have to move the patient up in the bed. Removing the ICU headboard and moving the bed down may provide the provider more room to maneuver.
- *P*retreatment
  - Lidocaine 2 min before intubation to be effective.
  - Opioid (fentanyl for CV disease or head injury).
  - Atropine (ready for non-hypoxemic bradycardia).
  - Defasciculating dose of paralytic (if using succinylcholine only)
- *P*aralysis – First induction agent and then paralytic given rapid IV push.
  - Remember – if no opioid was given, the induction agent and muscular paralytic have no effect on pain sensation.
- *P*lacement of airway
  - Confirm endotracheal tube placement with $EtCO_2$, SpO_2, breath sounds bilaterally, no sounds over epigastrium; secure the endotracheal tube.
- *P*ost-intubation management
  - Additional longer-acting sedation and muscular paralysis if needed; consider pain medication, hemodynamic and oxygenation monitoring, and appropriate ventilator settings. Chest radiograph for positioning/placement. It is common for patients to become hypotensive immediately post intubation, secondary to the administration of the induction agent and removing the patients' sympathetic response to respiratory distress. Patients may also have a small desaturation event immediately post intubation even in the presence of positive $ETCO_2$. It is often required to perform a few recruitment maneuvers immediately post intubation.

The Non-RSI Procedure

1. Assure patient is connected to appropriate monitors and reliable IV access is achieved. A large bore peripheral IV is recommended. Assemble equipment and suction. Prepare the ICU bed for intubation. Often the headboard needs to be removed to access the patient. The provider may need to move the patient up in

the bed to allow easy access for laryngoscopy. Moving the bed away from the wall is essential. Making these adjustments after induction/sedation will cost valuable oxygenation time.

2. If the patient is breathing at an adequate rate and volume, assure appropriate preoxygenation by utilizing a non-rebreather mask for at least 3 min (Figs. 5.2 and 5.3). If the patient is not breathing at an adequate rate or volume (minute ventilation), assist ventilations with a BVM device. If the patient does not demonstrate adequate ventilation (chest rise, increase in oxygen saturations, fog in the mask), it may be necessary to place a nasopharyngeal airway. Place with caution as blood in the airway can cause difficulty with intubation. If the patient is obtunded and the provider is able to place an oral airway, only a small dose of induction agent is needed. Often a light jaw thrust is all that is required to assist the patient. Preoxygenate with 100% oxygen for a minimum of 3 min or 8 vital capacity breaths (Figs. 5.4 and 5.5).

Complications

Hypotension

Failed recognition of an esophageal intubation (the gold standard is positive

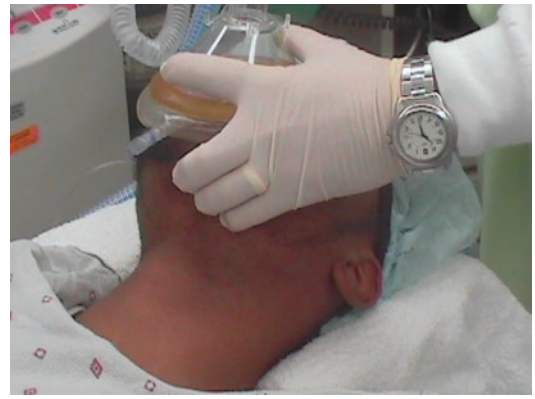


Fig. 5.3 Thumb and index finger form the letter C; other three fingers form the letter E

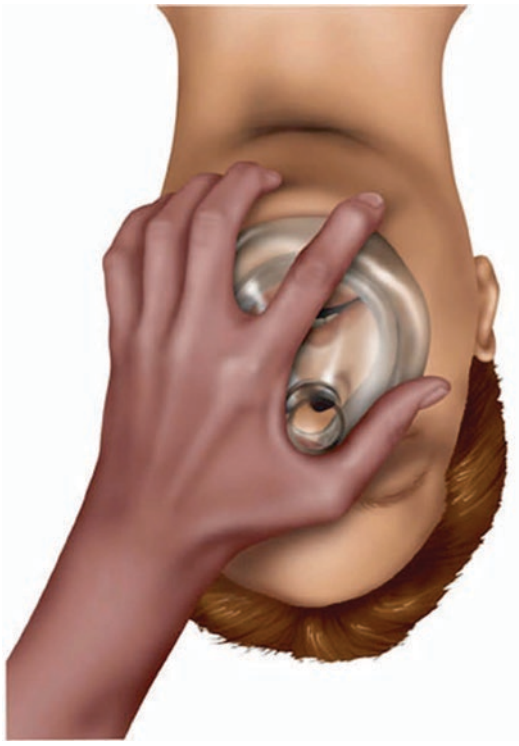


Fig. 5.2 Assure good mask seal

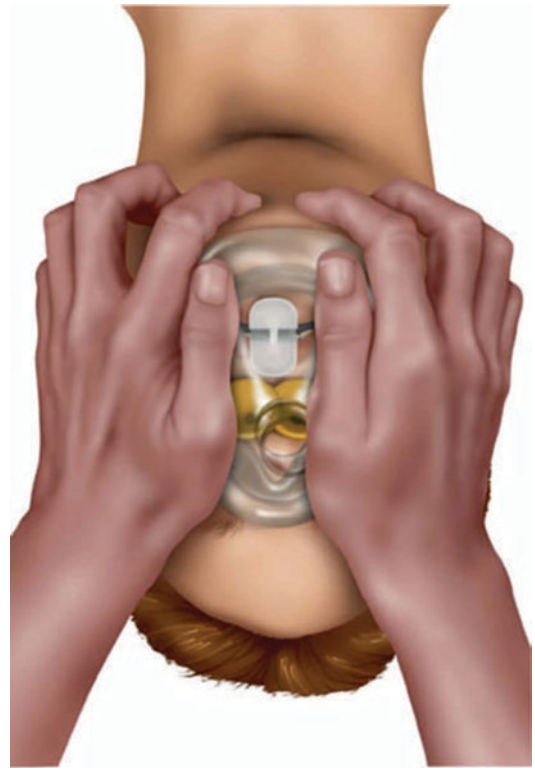


Fig. 5.4 Assure good seal – two-hand technique

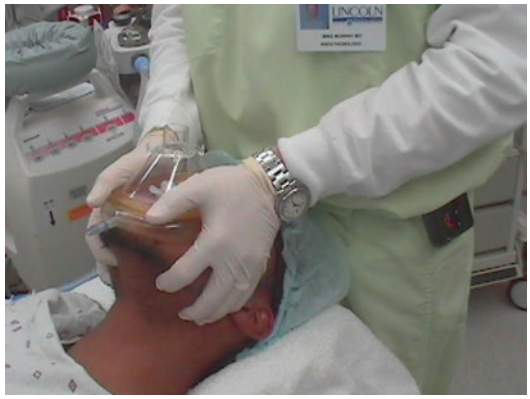


Fig. 5.5 Jaw thrust and mask seal

$ETCO_2$ after 5 breaths)
Damage to airway structures during attempt
Damage to teeth

Intubation Equipment

Oxygen, suction, oropharyngeal or nasopharyngeal airways (Figs.5.6 and 5.7)

Monitoring equipment (ECG, SpO_2, B/P, respiratory rate, $ETCO_2$)

Bag valve mask and/or non-rebreather oxygen mask

Endotracheal tubes

For most adult patients, consider sizes 7.0, 7.5, and 8.0. If bronchoscopy

procedure is to be completed, an 8.0 OETT is recommended.

Endotracheal tube stylet

Laryngoscope handle (contact versus fiber optic) (Fig. 5.8)

Laryngoscope blade

Macintosh (curved) sized 0–4 (adults usually 3 or 4) (Fig. 5.9)

Miller (straight) sized 0–4 (adults usually 2 or 3) (Fig. 5.10)

10 ml syringe (for ET tube cuff)

Commercial ET tube holder or ET tape

Colorimetric capnometer or qualitative end-tidal CO_2 monitor

Gum elastic bougie

Fig. 5.6 Oral airway

Fig. 5.7 Nasopharyngeal airway

Fig. 5.8 Laryngoscope handle

Video Laryngoscopy

The approach to airway management has undergone a dramatic transformation since the advent of videolaryngoscopy (VL). Each VL device has its own unique advantages and disadvantages. However, there are generalized advantages and disadvantages. Most VL devices offer significant advantages: lack of necessity to align airway axes (oral-pharyngeal-laryngeal) to achieve line of sight, improved glottic visualization (especially in scenarios with limited mouth opening or neck mobility), reduced cervical manipulation, high

Fig. 5.9 (**a**) Macintosh laryngoscope blade, (**b**) Macintosh laryngoscope blade and handle

Fig. 5.10 Miller laryngoscope blade

endotracheal intubation (ETI) success rate with non-expert laryngoscopists, and ability of others to view the screen or facilitate ETI (cricoid pressure, adjust/redirect, placement of bougie). It also is an effective tool for those who infrequently intubate and those learning to intubate and can provide a video/photograph for the official record. Lastly, VL allows possible awake assessment/intubation [5–7]. A potential limitation to VL is in the presence of large-volume secretions or blood in the oropharynx, which may make fiberoptic visualization problematic (Fig. 5.11a–d).

Endotracheal Intubation

1. If the laryngoscopist chooses to use a pre-intubation medication such as lidocaine, opioid, atropine, or a defasciculating dose of a neuromuscular blocker, now is the time to administer these medications.

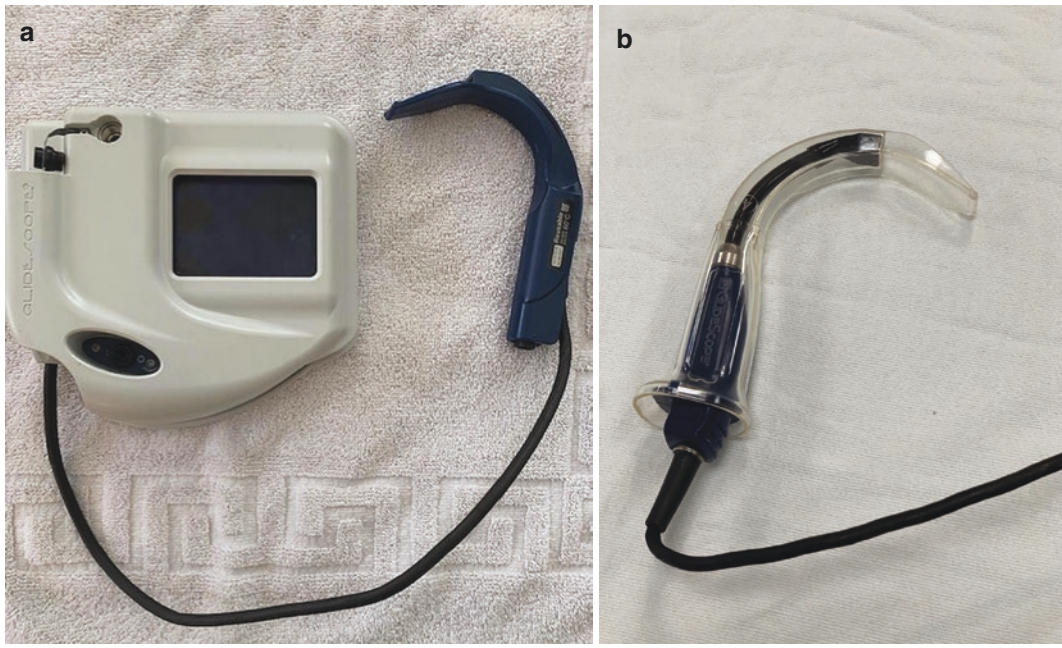


Fig 5.11 (**a**) Video laryngoscope, (**b**) video laryngoscope fiberoptic camera, (**c**) video laryngoscope view, (**d**) video laryngoscope placement

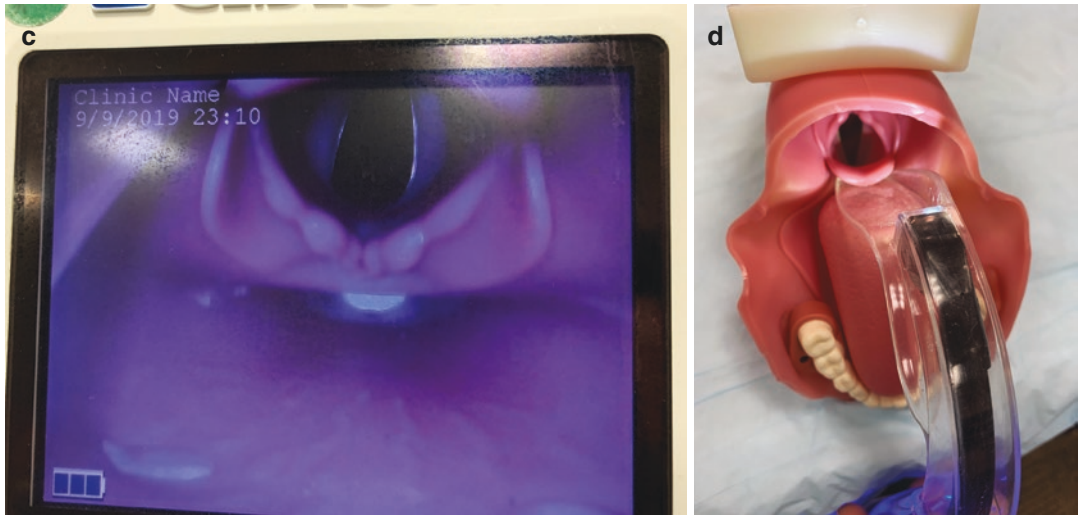


Fig 5.11 (continued)

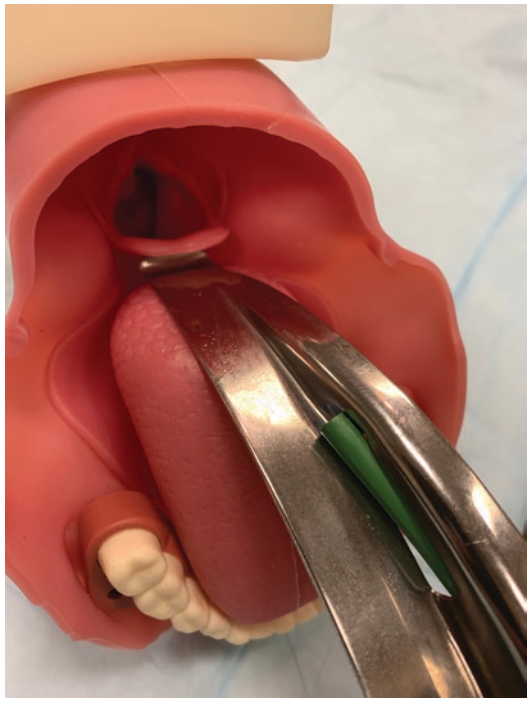


Fig. 5.12 Macintosh laryngoscope blade placement

2. Induction/sedation agent is given at this time. For hemodynamic instability (SBP < 90 mmHg), the sedative should be on the lower dose range. The neuromuscular blocker is never given at a reduced dose. Rapid sequence induction or intubation is given its name because the sedative is given rapid IV push followed immediately by the neuromuscular blocker IV push. Check for muscle flaccidity.
3. Insert the blade of choice and sweep the tongue from right to left.
   (a) If the Macintosh (curved) blade is used, the tip of the blade is placed at the base of the tongue (Fig. 5.12), and the mandible is displaced anteriorly until the epiglottis is raised to easily visualize the vocal cords.
   (b) If the Miller (straight) blade is used, the tip of the blade is placed under the epiglottis (Fig. 5.13) and is used to elevate the epiglottis to visualize the cords.
4. The endotracheal tube, with stylet in place and not extending beyond the tip of the ETT, is placed through the vocal cords and into the trachea under direct visualization. The ETT is placed at a depth of approximately three times the size of the ETT. For example, if placing an 8.0 ETT, it should be inserted to a depth of 24 cm at the teeth or lips. The stylet is removed, the cuff inflated, and confirmation assured by one or more of the following methods: $ETCO_2$ capnography, colorimetric capnography, auscultation of bilateral breath sounds and no sounds over the epigastrium

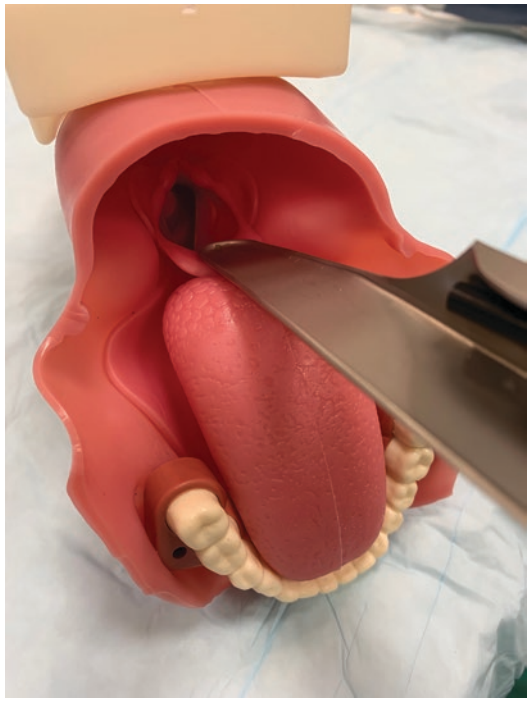


Fig. 5.13 Miller laryngoscope blade placement

with bag-assisted ventilations, or condensation in the ETT. Waveform qualitative capnography is considered the "gold standard" for proof of correct placement.

5. Once correct placement is confirmed, the ETT should be secured with a commercial ETT tube holder or ETT tape. A post-intubation chest X-ray should be ordered to confirm correct depth of the ETT.

Difficult Airways

The difficult airway algorithm was designed to help practitioners deal with both anticipated and unanticipated difficult airway management. Despite a myriad of recommendations, there will undoubtedly be an unanticipated difficulty with airway management. When navigating the difficult airway algorithm, decision points hinge on whether or not oxygenation and ventilation are adequate. The most important consideration for a decision point is whether mask ventilation is adequate. Once mask ventilation has been established, the urgency is removed, and the practitioner can use a different technique or awaken the patient. It is common practice to place a laminated copy of a difficult airway algorithm on your airway cart.

Billing Codes

J96.00: Acute respiratory failure, unspecified whether with hypoxia or hypercapnia

31500: Endotracheal intubation, emergency procedure

31605: Tracheostomy, emergency procedure, cricothyroid membrane

Summary

Only after a history and physical with concentration on airway assessment has been completed and the provider has determined the risks and benefits of interventional airway management should the procedure be performed. Preparation, familiarity, and anticipation are essential for successful airway management. Communication with all team members is a must prior to beginning. Verifying all equipment function, team assignments, positioning, and effective preoxygenation prior to the administration of an induction agent will increase the providers' chances for success. Once the induction agent has been administered, the clock has started. It is important to listen to the internal clock as you attempt endotracheal intubation. If unsuccessful after 60 seconds, establish mask ventilation and proceed down the difficult airway algorithm. The providers have many tools available for successful airway management. Rehearsal and familiarity with all aspects of interventional airway management will determine success. Good judgment comes from experience, and experience comes from bad judgment.

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Rescue Airway Devices and Techniques

6

Tanya Rogers and Dennis A. Taylor

Introduction

Rescue airway management in an actively decompensating patient is a common procedure performed in the intensive care unit (ICU) [1]. Due to the often limited physiological reserve of the critically ill patient, it is necessary that advanced practice providers (APPs) in the ICU are proficient and competent to utilize rescue airway equipment and techniques in the ICU to successfully secure an airway.

Indications

Failure to maintain an oxygen saturation above 90%, inability to secure an endotracheal tube in the trachea on the third attempt, and accidental extubation constitute a respiratory emergency and may necessitate the utilization of a rescue airway device in the ICU [2]. In addition, any "Can't Oxygenate/Can't Ventilate" situation requires rapid assessment of alternative airway devices and procedures to secure a patent airway.

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Contraindications

There are no contraindications to utilizing any of the rescue airway devices with the exception of the emergent cricothyrotomy. A cricothyrotomy should only be used in can't ventilate, can't oxygenate situations where a rescue device has also failed [2]. Please refer to the "Cricothyrotomy" chapter in this book.

Before any of the rescue airway techniques and devices discussed below are used, a basic assessment of the patient's airway needs to be performed by the provider to make an informed plan and identify an appropriate alternative approach if needed to secure the airway [3]. Please refer to the "Airway Management in the ICU"chapter in this book.

Equipment

Bag Valve Mask Ventilation

Bag valve mask (i.e., Ambu bag) is the standard in positive-pressure ventilation delivery for a patient who is not breathing at an adequate rate or volume (Fig. 6.1). It can be used before and between attempts at airway instrumentation and can assist in delivering the recommended 3 minutes of preoxygenation during the rescue phase of airway management [3]. Although the use of Ambu bags is deemed a necessary skill for all

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providers, it does pose risks if done improperly. Barotrauma and/or aspiration of gastric contents can be induced by overinflating the lung and gastric insufflation [4]. Only an amount of air necessary to cause chest rise and fall is needed for adequate ventilation.

Bag valve masks are face masks that have a one-way or PEEP valve, a compression bag, and oxygen tubing that attaches to an oxygen flowmeter capable of delivery up to 15 L/min of oxygen [5]. Proper patient positioning is critical. Techniques to optimize mask seal and decrease airway resistance/increase respiratory compliance include optimal head, mandible, and body position to improve upper airway patency and allow for proper ventilation [5, 6]. Oropharyngeal airway adjuncts in an unconscious patient can prevent the tongue from falling back, while a nasopharyngeal airway in a conscious patient can help to improve upper airway patency [4]. Implemented properly, bag valve mask ventilation can be performed indefinitely until a secure airway can be placed. Please refer to your specific BVM manufacturer for details on the percentage of oxygen actually delivered to the patient during ventilations with the BVM. It *is not* always 100%. Many BVMs deliver significantly less than 100% oxygen due to the air entrainment pathway of the BVM.

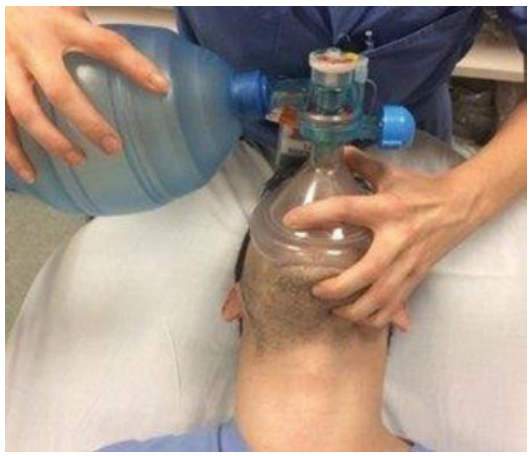

Fig. 6.1 BVM applied to patient using C/E technique

The "EC clamp" technique (Fig. 6.2) is one in which the rescuer grasps the face mask using their palm, thumb, and index finger and, while making a "C" over the face mask, places the face mask with the pointed end of the mask over the

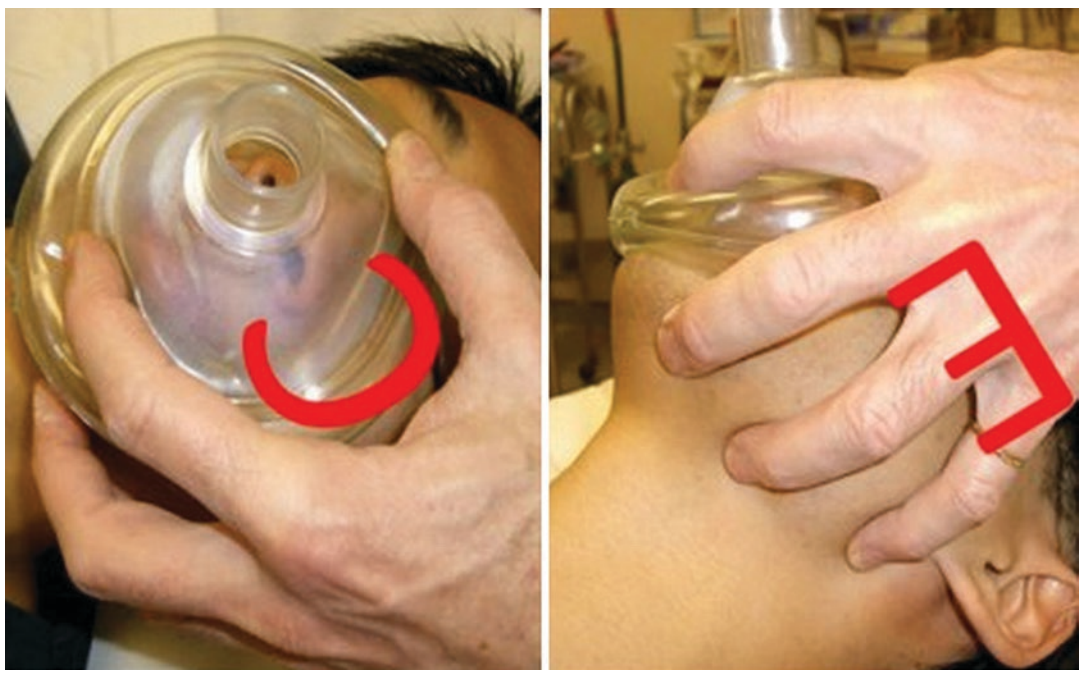

Fig. 6.2 C/E technique for BVM

patients nose while the other end goes below the patient's lower lip [4, 5]. Using the remaining fingers, the rescuer makes an "E" at the patient's jaw and anchors the hand to the face while gently pulling up on the patient's jaw to create a jaw thrust and minimize leaks around the mask [4, 5]. With the other hand or with assistance of a second rescuer, the rescuer squeezes the bag while watching for the patient's chest to rise and fall and for maintenance or improvement of oxygen saturation.

High-Flow Nasal Cannula (Optiflow)

High-flow nasal cannula (Fig. 6.3) is a rather recent development in rescue airway management [7]. It can be used as an adjunct with bag valve mask ventilation or in an apneic patient to assist with preoxygenation during or while waiting to intubate a patient to prevent desaturation and hypoxemia [6]. Unlike a standard low-flow nasal cannula delivering only 6 L/min or 40% FiO_2, a high-flow nasal cannula delivers up to 60 L/min or 100% FiO_2 of heated and humidified oxygen via the nasal route [7–9]. The high-flow nasal cannula can actually deliver a small amount of passive positive end-expiratory pressure (PEEP).

The high-flow nasal cannula delivery systems consist of a flow meter, active heated humidifier, heated inspiratory circuit, air-oxygen blender, and nasal cannula [9]. The air-oxygen blender delivers a heated and humidified gas through the heated inspiratory circuit to the patient through a large-diameter nasal cannula and is secured with a head strap [9]. Once placed into the patient's nares, it not only is beneficial in the immediate rescue airway but also has the prolonged benefits of washing out carbon dioxide in anatomical dead space while adding a small amount of PEEP to recruit alveoli [8, 9].

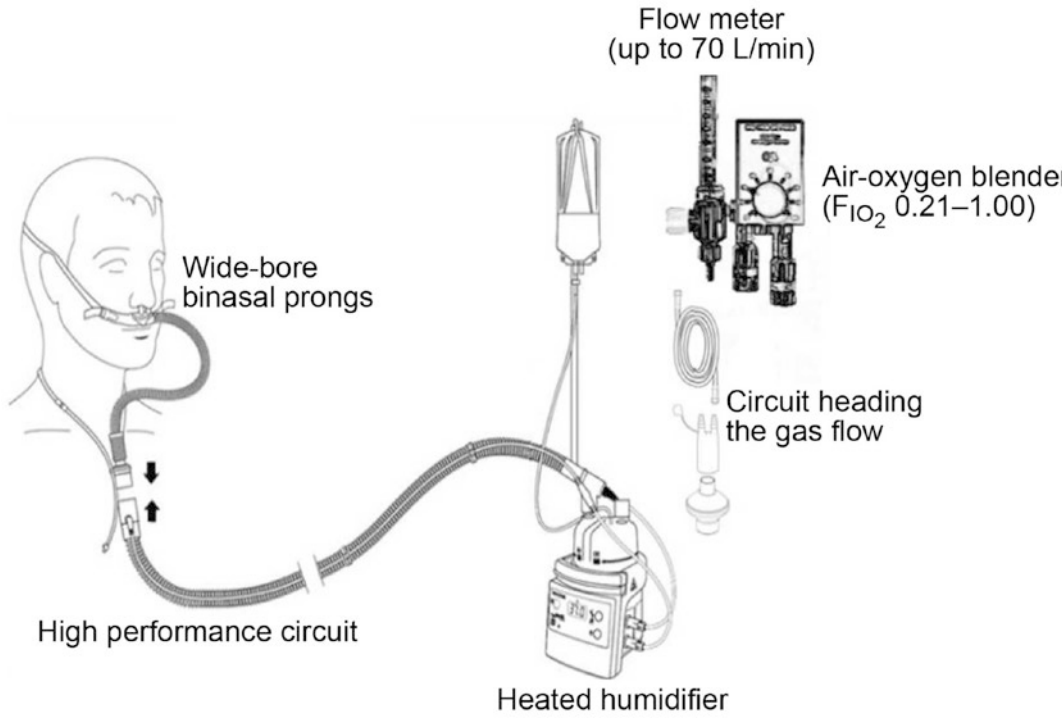

Fig. 6.3 High-flow oxygen set-up

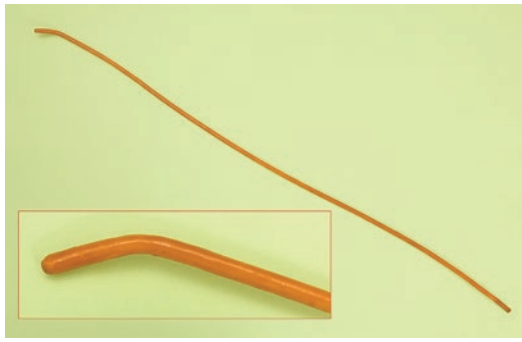

Fig. 6.4 Gum elastic bougie

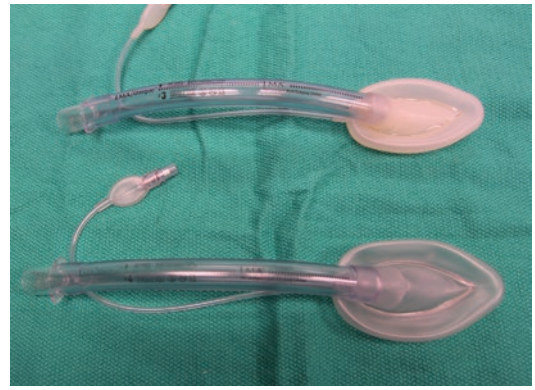

Fig. 6.5 Laryngeal mask airway (LMA)

Bougie (Gum Elastic Bougie)

Endotracheal tube introducer (ETI) a.k.a. gum elastic bougie (Fig. 6.4) is used to facilitate intubation in patients with difficult to visualize vocal cords [7]. Once the bougie is in the airway, an endotracheal tube can be "railroaded" over the device into the airway, after which the bougie is removed. Some devices have a removable adapter that can be used to ventilate the patient if needed during the exchange procedure.

The ETI is a long (60 cm) narrow (5 mm) device with a fixed 40 degree bend at the distal end (coude tip) (Fig. 6.4). The ETI is held with the tip pointed upward-upon visualization of the epiglottis; the tip is directed under the epiglottis and advanced. As the ETI is advanced, it will enter the trachea, and the coude tip will rub against the anterior portion of the trachea. This will produce a vibration as the tip rubs against the anterior tracheal rings. Tracheal placement can also be confirmed by a hard stop at approximately 40 cm of insertion. Placement in the esophagus will not result in a hard stop. The endotracheal tube is then placed over the ETI while the intubator keeps the laryngoscope in place.

Supraglottic Airways

Presently, there are multiple types of supraglottic airways on the market. Emphasis on the use of supraglottic airways or laryngeal mask airways (LMAs), i-gel airways, and King LT airways as rescue devices has gained traction in the last few years due to their mechanism for gastric drainage which may prevent aspiration during placement [6]. LMA and i-gel placement requires minimal training to use, can be placed without trauma, and can be a conduit for fiberoptic-guided tracheal intubation [6].

Supraglottic Devices

The Laryngeal Mask Airway (LMA)

LMAs come in a variety of sizes that typically depend upon the patient's weight (Fig. 6.5). For adults, the typical scale is a size 3 for 30–50 kg, size 4 for 50–70 kg, and size 5 for >70 kg. The LMA is inserted as follows:

1. Completely deflate the cuff (if LMA is cuffed with air). Lubricate the cuff with a water-soluble lubricant.
2. Open the airway by using the head-tilt maneuver. A jaw-lift maneuver is often used and beneficial.
3. Insert the LMA into the mouth with the laryngeal surface directed caudally and the tip of your index finger resting against the cuff-tube junction. Press the device onto the hard palate, and advance it over the back of the tongue as far as the length of the index finger will allow (Fig. 6.6). Then use your other hand to push the device into its final seated position, allowing the natural curve of the device to follow the natural curve of the oropharynx (Fig. 6.7).

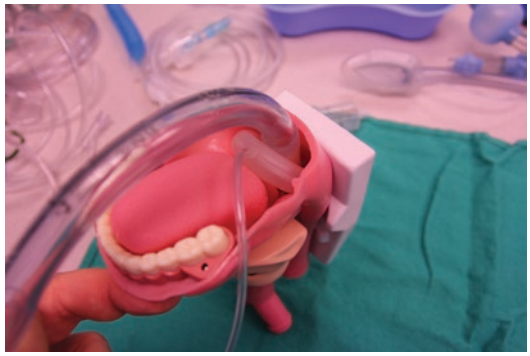

Fig. 6.6 LMA placement at the posterior pharynx

Fig. 6.7 LMA placement at the epiglottis

4. Inflate the collar with air (20–40 ml depending upon the size of the LMA) or until there is no leak with bag ventilation).

King LT (Laryngotracheal) Airway

The King LT airway is a latex-free single-lumen silicon laryngeal tube with oropharyngeal and esophageal low-pressure cuffs, with a ventilation port located between the two cuffs. The King LT (Fig. 6.8) is sized by height (see package for guidance). They come in two varieties: blind distal tip (King LT, LT-D) and open distal tip (King LTS, LTS-D) to permit gastric decompression (Figs. 6.9, 6.10, and 6.11). A single pilot balloon port is used to inflate both cuffs simultaneously (Fig. 6.12). The King LT is inserted as follows:

1. The King LT is designed to go only into the esophagus. The airway is opened with a head-tilt maneuver (Fig. 6.13).

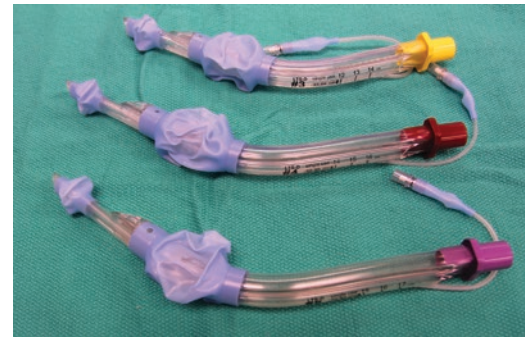

Fig. 6.8 Various sizes of King LT airway

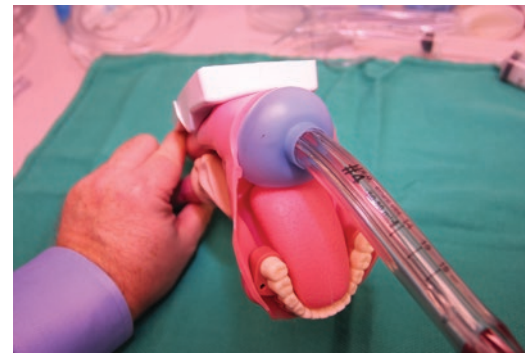

Fig. 6.9 King LT airway with occlusive balloon inflated

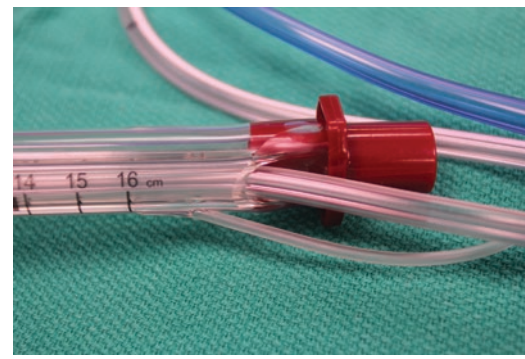

Fig. 6.10 King LT-D port for gastric tube

2. It is advanced until definitive resistance is felt or the colored flange touches the incisors.
3. The cuffs are inflated simultaneously with a single pilot bulb. The amount of air is dependent upon the size of the King LT airway (see device for exact amount).
4. Use a bag device to ventilate the patient. If an air leak is encountered, reassess the amount of air in the cuffs (Fig. 6.14).

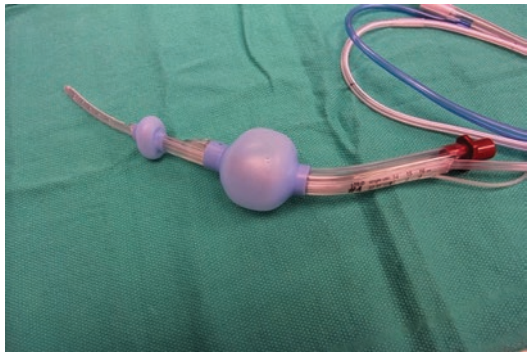

Fig. 6.11 King LT-D with gastric tube exiting at the end of airway

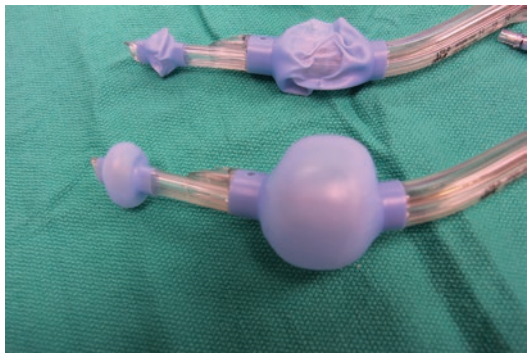

Fig. 6.12 King LT with both balloons inflated

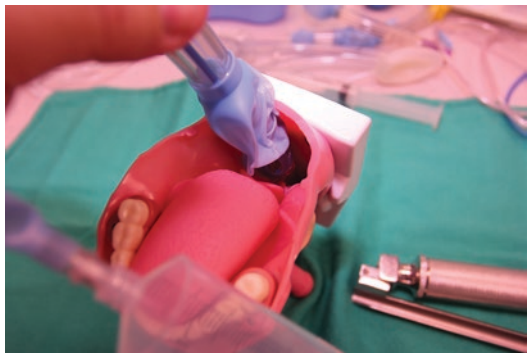

Fig. 6.13 Deflated cuff for insertion of King LT

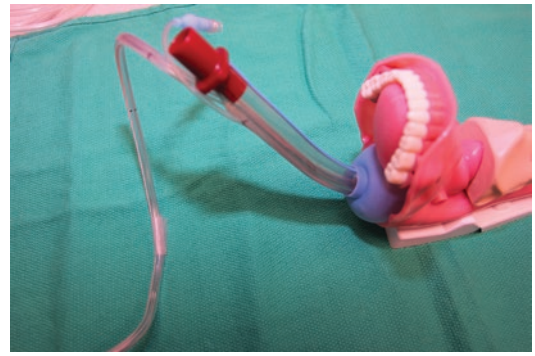

Fig. 6.14 Amount of air in cuffs of King LT with gastric tube

Fig. 6.15 i-gel sizes

i-gel

The i-gel® is a second-generation supraglottic airway device from Intersurgical. The first major development since the laryngeal mask airway, i-gel has changed the face of airway management and is now widely used in anesthesia and resuscitation. Made from a medical-grade thermoplastic elastomer, i-gel has been designed to create a non-inflatable, anatomical seal of the pharyngeal, laryngeal, and perilaryngeal structures while avoiding compression trauma.

i-gel is supplied in an innovative, color-coded protective cradle (adult sizes) (Figs. 6.15 and 6.16) or cage pack (pediatric sizes), to ensure the product is maintained in the correct flexion prior to use, important for patient safety and product performance, and to optimize gas circulation for effective sterilization. The cradle and cage pack also acts as a base for lubrication.

Indications

The i-gel is indicated for use in securing and maintaining a patent airway in routine and emer-

Fig. 6.16 i-gel protective cradle

gency anesthetics of fasted patients, during spontaneous or intermittent positive-pressure ventilation, during resuscitation of the unconscious patient, and as a conduit for intubation under fiberoptic guidance in a known difficult or unexpectedly difficult intubation, by personnel who are suitably trained and experienced in the use of airway management techniques and devices.

Contraindications

1. Non-fasted patients for routine and emergency anesthetic procedures.
2. Trismus, limited mouth opening, pharyngoperilaryngeal abscess, trauma, or mass.
3. Do not allow peak airway pressure of ventilation to exceed 40 cm H_2O.
4. Do not use excessive force to insert the device or nasogastric tube.
5. Inadequate levels of anesthesia which may lead to coughing, bucking, excessive salivation, retching, laryngospasm, or breath holding, thus complicating the anesthetic outcome.
6. Do not leave the device in situ for more than 4 hours.
7. Do not reuse or attempt to reprocess the i-gel.
8. Patients with any condition which may increase the risk of a full stomach, e.g., hiatus hernia, sepsis, morbid obesity, pregnancy, a history of upper gastrointestinal surgery, etc.
9. Use on a conscious/semiconscious patient in an emergency setting.

Insertion Technique

Preparation

- Inspect the packaging and ensure it is not damaged prior to opening.
- Inspect the device carefully, check the airway if it is patent, and confirm if there are no foreign bodies or a *bolus* of lubricant obstructing the distal opening of the airway or gastric channel.
- Carefully inspect inside the bowl of the device, ensuring surfaces are smooth and intact and also that the gastric channel is patent.
- Discard the device if the airway tube or the body of the device looks abnormal or deformed.
- Check whether the 15 mm connector fits the patient connection.

Insertion

1. Always wear gloves.
2. Open the i-gel package and on a flat surface take out the protective cradle containing the device.
3. In the final minute of preoxygenation, remove the i-gel and transfer it to the palm of the same hand that is holding the protective cradle, supporting the device between the thumb and index finger. Place a small bolus of a water-based lubricant, such as K-Y Jelly, onto the middle of the smooth surface of the cradle in preparation for lubrication. Do not use silicone-based lubricants.
4. Grasp the i-gel with the opposite (free) hand along the integral bite block and lubricate the

back, sides, and front of the cuff with a thin layer of lubricant. This process may be repeated if lubrication is not adequate, but after lubrication has been completed, check that no *bolus* of lubricant remains in the bowl of the cuff or elsewhere on the device. Avoid touching the cuff of the device with your hands.

5. Place the i-gel back into the cradle in preparation for insertion. NB. The i-gel must always be separated from the cradle prior to insertion. The cradle is not an introducer and must never be inserted into the patient's mouth.

A proficient user can achieve insertion of the i-gel in less than 5 seconds.

1. Grasp the lubricated i-gel firmly along the integral bite block. Position the device so that the i-gel cuff outlet is facing toward the chin of the patient (Fig. 6.17).
2. The patient should be in the "sniffing the morning air" position (Fig. 6.18) with the head extended and the neck flexed. The chin should be gently pressed down before proceeding to insert the i-gel.
3. Introduce the leading soft tip into the mouth of the patient in a direction toward the hard palate.

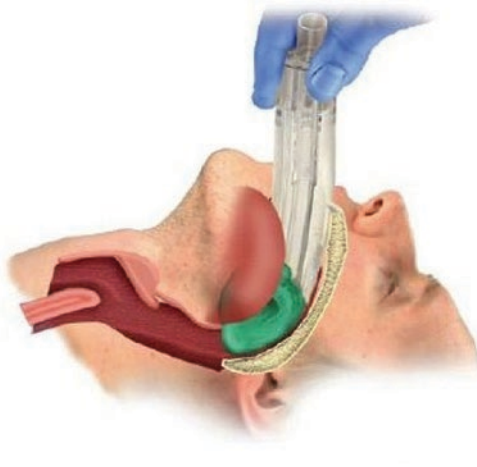

Fig. 6.17 i-gel position for insertion

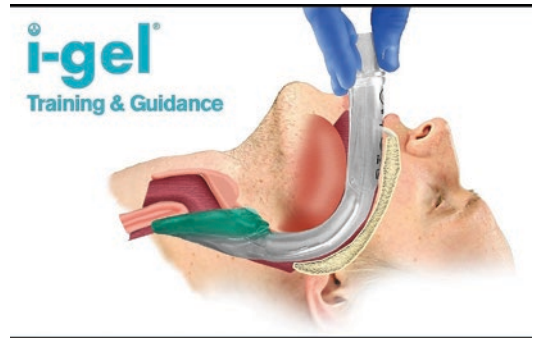

Fig. 6.18 Final position of i-gel

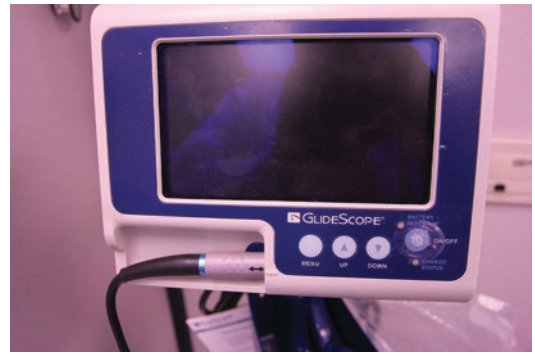

Fig. 6.19 GlideScope

4. Glide the device downward and backward along the hard palate with a continuous but gentle push until a definitive resistance is felt.
5. At this point, the tip of the airway should be located into the upper esophageal opening (Fig. 6.19), and the cuff should be located against the laryngeal framework. The incisors should be resting on the integral bite block.
6. i-gel should be taped down from "maxilla to maxilla."
7. If required, an appropriate size nasogastric tube may be passed down the gastric channel.

Video Laryngoscopy

In recent years, there has been a significant increase in the use of video laryngoscopy (VL) in all medical arenas because of advances in technology that have enabled VL to be more portable, to provide real-time video and higher-res-

olution images and with proper training, and to be used easier than devices of similar design [1, 10]. VL improves the view of the glottis from outside the patient's mouth without the need to manipulate the airway, thereby reducing potential injury to the patient's oral airway or neck [7]. Despite all of VL's strengths, it is limited by it's expense, considerable training and repetition, fogging or secretions obscuring the view, loss of depth perception, and the need for significant hand-eye coordination [7, 10]. VL is now being used regularly in the ICU for rescue, routine, and predicted difficult airways as a means to decrease intubation attempts and the need for adjunct rescue airway techniques [1, 10].

Video Laryngoscopy

(a) GlideScope video laryngoscope (Fig. 6.19)
(b) GlideScope cobalt/cobalt AVL
(c) GlideScope ranger
(d) Storz C-MAC (Fig. 6.20)

Procedure

1. Prepare the equipment.
   - Plug into power source.
   - Use handle/blade cover as needed.
   - Use specific stylette for equipment.
   - Load stylette into the endotracheal tube (Fig. 6.21).
   - Test ETT cuff.

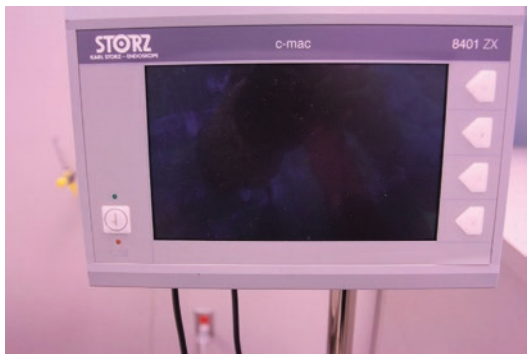

Fig. 6.20 Storz C-MAC

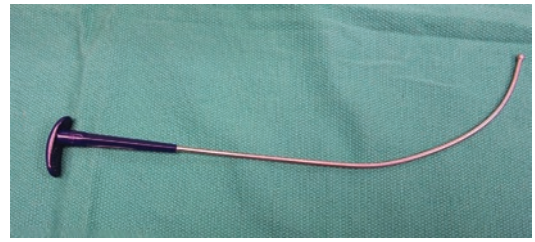

Fig. 6.21 Stylet for C-MAC

   - Have suction available.
   - Appropriately preoxygenate and pre-medicate.
2. Look into the mouth.
3. Place the blade in the middle of the tongue (do not sweep the tongue as you would in the traditional intubation process).
4. Watch the video screen and visualize anatomic landmarks.
5. Place the ETT tube through the cords.
6. Confirm placement via waveform capnography and/or end-tidal carbon dioxide detector.
7. Secure the ETT.

Summary

As advanced care practitioners, the most important factors in rescue airway management are having familiarity and continual training on the available equipment, anticipating the need for an alternative strategy or device, and effectively communicating with the team members to ensure a successful airway intervention [1]. It is recommended to develop a standardized evidence-based protocol or bundle in rescue airway management in order to discourage emergency airway complications in the ICU [11].

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Cricothyroidotomy

7

Jonathan A. Messing and Babak Sarani

Introduction

Cricothyroidotomy, also referred to as a cricothyrotomy, is an emergency airway procedure for patients in respiratory distress whose oxygenation and ventilation needs cannot be met via either bag-valve-mask (BVM) ventilation or invasive ventilation. The classic patients to benefit from this emergent procedure are those patients in a "cannot ventilate, cannot oxygenate" clinical scenario [1–3]. Patients who can be supported with BVM, supraglottic airways (e.g., laryngeal mask airways (LMA), or esophageal airways – e.g., King/Combitube™) do not require a cricothyroidotomy. For the provider, cricothyroidotomy is a rescue maneuver permitting very little time for deliberation. Proceduralists will claim that the hardest step in performing a cricothyroidotomy is making the decision to perform one in the first place. Patients requiring emergency surgical airways are in imminent danger with only minutes to seconds remaining before complete cardiovascular collapse due to severe hypoxemia and hypercapnia with resultant cardiac arrest, cerebral anoxia, and death.

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Surgical airways have been described since the Egyptian times, with cricothyroidotomy evolving over the nineteenth century. It wasn't until the 1900s that cricothyroidotomy became more commonplace, thanks to Dr. Chevalier Jackson, but the risk of post-procedural tracheal stenosis curtailed its use [4]. Currently, performing a cricothyroidotomy is recognized as a rapid means of definitively securing the airway when other options have failed.

Due to the surrounding circumstances of any emergency, the procedure does not offer the usual benefits of planning, orchestrating a time-out, and a full set of instruments. In order to facilitate success, it is essential that proceduralists practice cricothyroidotomy routinely using simulations, cadavers, and other models [2, 5]. Although a standard surgical cricothyroidotomy is the preferred method when indicated, variations do exist. Providers can perform a needle cricothyroidotomy using a 14-gauge needle and apply percutaneous transtracheal oxygenation (PTO) or jet insufflation. These strategies are temporizing measures that will result in hypercapnia but will facilitate oxygenation for up to 30 or 45 minutes, until a more definitive airway is obtained. Both methods can yield different physiology when applied and result in barotrauma [6]. When performing PTO, the provider connects oxygen at 15 L/min to the needle using a Y connector or stopcock [5, 7]. Instructions are to administer the oxygen for 1 second and then release for

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4 seconds [6, 7]. Alternatively, jet insufflation can be applied. The biggest obstacle to needle cricothyroidotomy with jet insufflation is having ready access to the jet insufflator.

More similar to the standard cricothyroidotomy is a four-step approach. The four-step approach affords a more direct process when fewer resources are available [2]. The provider identifies landmarks, makes a vertical incision, stabilizes the trachea, and inserts the artificial airway. Finally, some data exist for performing a surgical cricothyroidotomy with household materials; however, this topic is beyond the scope of this chapter and the acute care environment [8].

When determined necessary, a rapid prep can be performed but should not delay the procedure. Although chlorhexidine gluconate is often contraindicated in airway procedures due to electrocautery use, proximity to high-flow oxygen, and fire risk, a cricothyroidotomy is rarely performed with electrocautery and therefore not at risk for a surgical fire [9]. That said, Betadine is preferable in this situation due to the requisite 3 minutes chlorhexidine gluconate needs to dry to be effective [9]. Providers should use their judgment on available materials and need to proceed.

Using the nondominant hand to secure the trachea, the provider should identify the cricothyroid membrane by palpating below the thyroid cartilage and above the cricoid cartilage. Ideally, a right-hand dominant provider should stand on the patient's right side to facilitate this approach [2]. Left-hand dominant providers may stand on the patient's left side. A vertical incision can be made with a scalpel, preferably an 11 blade, followed by a horizontal incision through the cricothyroid membrane itself. Vertical incisions permit extension cephalad or caudad as necessary, as a larger incision can be amended after the airway is secure. Furthermore, vertical incisions limit the risk of injuring blood vessels, which are typically positioned just off of the midline on either side of the trachea [5].

A tracheal hook can be used to grasp and pull the trachea anteriorly before or after incising into the airway. A Trousseau dilator can be used to further dilate the incision in the cricothyroid membrane. If a dilator is unavailable, the blunt end of the scalpel may be utilized for dilation by inserting and twisting. A hemostat may also be applied for dilation if other options are unavailable. A bougie can be inserted and used to guide insertion of a tracheostomy or endotracheal tube into the airway [5]. A cuffed 4.0 or 6.0 Shiley tracheostomy tube may then be introduced. Alternatively, an endotracheal tube may be placed if a tracheostomy tube is not available. A 4.0 Shiley tracheostomy tube is preferable due to the diameter of the cricothyroid membrane being as small as 9 mm, its shorter length that makes placement into the right bronchus less likely, and its flange that allows it to be secured to the neck more readily than an endotracheal tube [2].

Of note is the existence of commercially available cricothyroidotomy kits (Fig. 7.1). Various vendors exist and providers should familiarize themselves as per the contents of each package if present in their institution. Again, emphasis is placed on the emergent nature of a cricothyroidotomy and the need to prepare with and without a kit even if one's institutions provides them.

Indications

Failure to provide an airway via the mouth/nose
Inability to oxygenate and ventilate
Oropharyngeal hemorrhage

Fig. 7.1 Manufactured cricothyroidotomy kit. [Permission for use granted by Cook Medical, Bloomington, Indiana]

Foreign body obstruction
Significant maxillofacial trauma
Angioedema or upper airway edema
Laryngeal fracture with loss of the airway

Contraindications

There is no absolute contraindication to performing a cricothyroidotomy in adult patients. Some will argue that the procedure is contraindicated in patients under 12 years of age; however, these authors will state the emergent nature of the procedure makes pediatrics a relative contraindication [2].

Relative contraindications include:
Tracheal transection [4]
Laryngotracheal disruption [4]
Coagulopathy
Local infection

Risks/Benefits

The primary risks of this emergent and potentially lifesaving procedure involve an inability to appropriately secure the airway, oxygenate, and ventilate the patient. Additional risks include injury to the airway and hemorrhage. A delay in rapidly securing the airway may result in anoxic brain injury. Failure to secure the airway may result in loss of life. Whereas it is possible to injure surrounding structures, such as the thyroid cartilage or thyroid gland, such injuries are rarely clinically significant and can be addressed once the airway has been secured.

Preparation

1. Rapid identification of the need to perform a cricothyroidotomy is the most important step of the procedure. This may start with verbalization to a resuscitation team that you are proceeding with the procedure.
2. Position the patient supine. If not contraindicated, extend the neck in order to mobilize the trachea anteriorly. Contraindications of cervical extension include suspected cervical spine injury or immobilization devices (e.g., halo device).
3. Gather minimum equipment needed:
   (a) Scalpel
   (b) Hemostat and/or Trousseau dilator (optional but preferred)
   (c) Tracheal hook (optional but preferred)
   (d) Artificial airway
      (i) 4.0 cuffed Shiley (preferred)
      (ii) 6.0 cuffed Shiley
      (iii) Endotracheal tube (size 6.0)
   (e) Sterile gauze
   (f) 10 mL syringe
   (g) Suture and needle driver
   (h) Bag-valve mask
   (i) Ventilator
   (j) End-tidal CO_2 detector
   (k) Bougie (optional but preferred)
4. If using a 4.0 or 6.0 Shiley, prepare it by removing the inner cannula, ensuring complete deflation of the balloon, inserting the obturator, and applying a water-based lubricant. Remove the inner cannula but do not insert the obturator if using a bougie.

Procedure

Surgical Cricothyroidotomy

1. If time permits, prep the area over the anterior neck with Betadine and provide appropriate draping. Note: chlorhexidine gluconate is an acceptable alternative; however, this preparation provides limited effectiveness without the necessary 3-minute time for drying, which is precluded by the emergent nature of the procedure.
2. Using the nondominant hand, the provider should stabilize the trachea.
3. Locate the cricothyroid membrane below the thyroid cartilage and above the cricoid cartilage (Fig. 7.2).
4. Make a 2 cm vertical incision over the cricothyroid membrane (Fig. 7.3a).

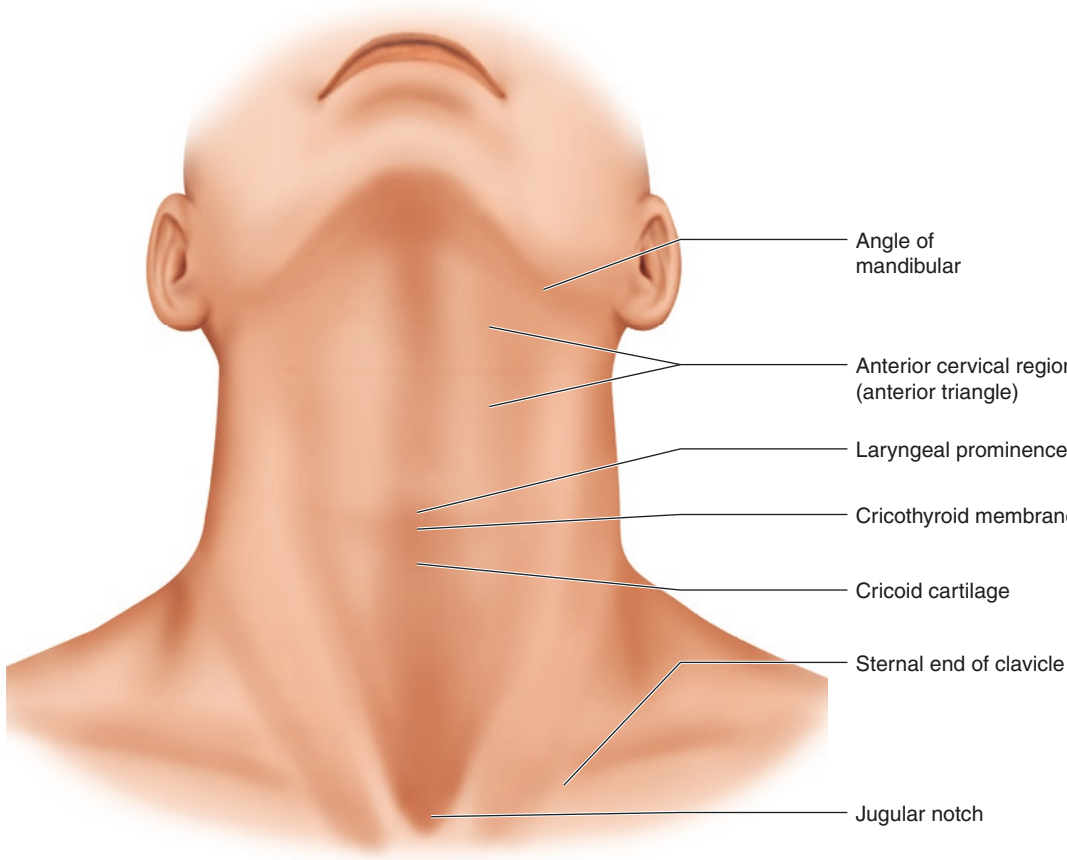

Fig. 7.2 Anterior neck, extended, with external anatomy noted

5. Incise a horizontal incision through the cricothyroid membrane (Fig. 7.3b).
6. If possible, using the tracheal hook, grasp the trachea in the caudad direction and lift anteriorly (Fig. 7.3c).
7. Using the dilator, a hemostat, or the blunt end of the scalpel, dissect/dilate the incision through the cricothyroid membrane (Fig. 7.3d).
8. Insert the bougie or prepared tracheostomy or endotracheal tube.
9. If using a tracheostomy tube, insert the inner cannula. If using an endotracheal tube, cut the tube as close as possible to the pilot balloon port to shorten it.
10. Ventilate the patient with a bag-valve device and confirm bilateral breath sounds as well as end-tidal CO_2 to ensure that the tube is in the airway.
11. Connect the tracheostomy or endotracheal tube to the ventilator or other ventilation assist device.
12. Secure the tracheostomy or endotracheal tube with sutures.

Alternative Interventions

Needle Cricothyroidotomy

1. If time permits, prep the area over the anterior neck with Betadine and provide appropriate draping.
2. Using the nondominant hand, the provider should stabilize the trachea.

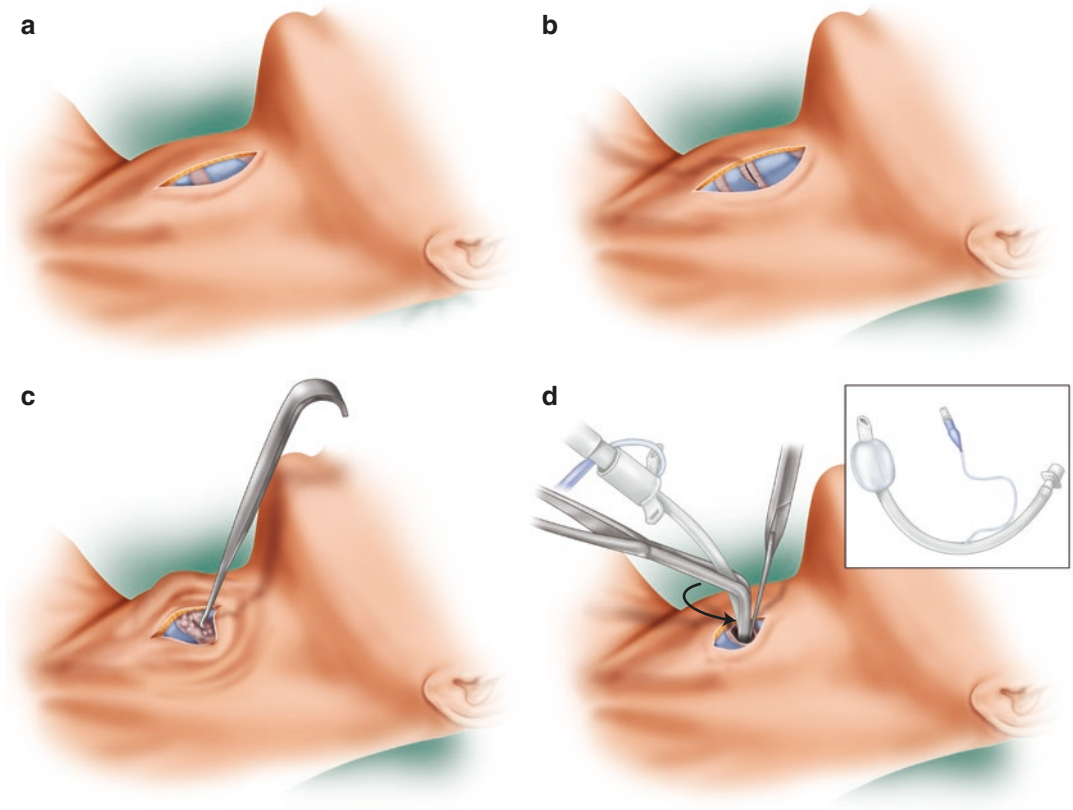

Fig. 7.3 (**a**) Vertical incision over the cricothyroid membrane, (**b**) horizontal incision through the cricothyroid membrane, (**c**) tracheal hook used to stabilize and secure the trachea anteriorly, (**d**) insertion of tracheostomy tube

3. Locate the cricothyroid membrane below the thyroid cartilage and above the cricoid cartilage.
4. Insert a 14-gauge or larger needle through the cricothyroid membrane in the caudad direction (Fig. 7.4).
5. Advanced until air is aspirated.
6. Connect oxygen at 15 L/min to the needle using a Y connector for the PTO method or apply a jet insufflator.
7. Secure the needle with suture material.
8. If using the PTO method, administer oxygen for 1-second duration by covering the free end of the Y connector, alternating with 4 seconds of releasing oxygen flow by unobstructing the other end of the Y connector.
9. Repeat step 8 for a maximum of 30–45 minutes or continue to use the jet insufflator.
10. Prepare for definitive airway.

Rapid Four-Step Approach

1. Locate the cricothyroid membrane below the thyroid cartilage and above the cricoid cartilage.
2. Make a 2 cm vertical incision through the skin and the cricothyroid membrane.
3. Insert the tracheal hook into the inferior portion of the incision and lift the trachea anteriorly.
4. Insert the prepared tracheostomy or endotracheal tube.

Complications

Most bleeding associated with a cricothyroidotomy is venous or from a small laceration in the thyroid gland. In either instance, bleeding is slow and will stop with pressure. Thus, the wound can

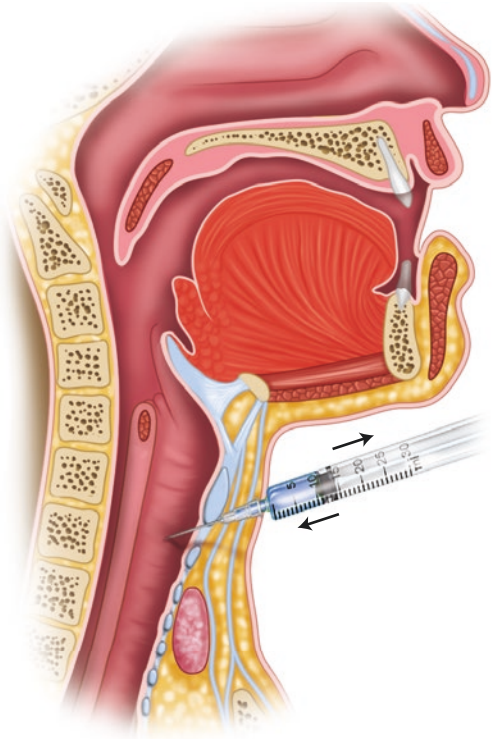

Fig. 7.4 Needle insertion through the cricothyroid membrane

be packed around the tracheostomy/endotracheal tube with gauze or any hemostatic product. If this does not stop the bleeding, a more directed approach can be fashioned once the patient's overall condition is stabilized [2].

Accidental placement of the airway into the right bronchus is very common if an endotracheal tube is used as the definitive airway. The tube should only be inserted to a point where the balloon is situated in the airway. If breath sounds are absent on the left side, the endotracheal tube should be pulled back slowly.

It is very easy to create a false passage when attempting to place a tube into the airway. This possibility is higher in obese patients who have a lot of soft tissue that may hinder placement of the tube into the airway. False passage can be avoided by using a tracheal hook to deliver the airway into the incision and using a bougie to direct the tube into the airway using a Seldinger technique. The best method to assure that the airway has been secured is with confirmation of end-tidal CO_2 return and the presence of bilateral breath sounds. Inability to ventilate a patient (i.e., deliver air) after placement of the tube into the airway is a highly suggestive sign that the tube is in a false passage [2].

Keys to Success, Perils, and Pitfalls

- Ensure that the tracheostomy or endotracheal tube balloon is fully deflated before insertion.
- Make a vertical incision to limit bleeding and avoid multilevel incisions.
- Reduce fire risk by avoiding chlorhexidine gluconate and electrocautery.
- Avoid directing instruments cephalad after incision in order to prevent injury to the vocal cords [10].

CPT Coding

31605 – Tracheostomy, emergency procedure, cricothyroid membrane [11]

Summary

Cricothyroidotomy is a potentially lifesaving intervention when a patient is in respiratory distress and the medical team is unable to support oxygenation or ventilation. As a rescue maneuver, the procedure does not permit advanced planning with the exception of providers seeking simulation and routine practice in general. When needed, a cricothyroidotomy is often performed after several alternative attempts at airway placement and a period of lost time in doing so. Therefore, the decision to intervene with a cricothyroidotomy should be swift in order to avoid a suboptimal outcome.

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Additional Resources

Cricothyroidotomy video on MyATLS mobile app.

8 Percutaneous Dilatational Tracheostomy, Open Surgical Tracheostomy and Management of Tracheostomy Tubes

Scott P. Sherry

Introduction

Acute respiratory failure often leads to the placement of an oral endotracheal tube and the subsequent need for mechanical ventilatory support. Due to the varying degrees of critical illness and the development of ventilator dependence, patients are often subjected to prolonged periods of discomfort, sedation, airway secretion management, ventilator-associated pneumonia, and deconditioning. Prolonged intubation may also lead to tracheal stenosis and laryngeal injury [1–3].

In order to provide patients with a safe mechanism to wean from the ventilator, improve on delirium, and promote mobility, the placement of a tracheostomy is often employed. Both open surgical tracheostomy (OST) and percutaneous dilatational tracheostomy (PDT) are important procedures for long-term management of patients requiring mechanical ventilation. Tracheostomy helps to provide patient comfort and helps facilitation of weaning and liberation from mechanical ventilation [1–3]. These interventions require at least two skilled, knowledgeable proceduralists. A multidisciplinary team approach is paramount given the need for qualified staff to accomplish multiple near-simultaneous tasks. Physician assistants (PA) and nurse practitioners (NP) can provide the skills necessary and are considered to be an integral part of this multidisciplinary team.

This chapter will focus on traditional open surgical tracheostomy (OST) and the modern technique of percutaneous dilational tracheostomy (PDT) first described in 1985 by Caliga [4]. PDT is a commonly performed procedure in the intensive care unit [2, 3, 5]. It has fewer complications than traditional open tracheostomy and has gained wide acceptance as the preferred method of tracheostomy [2, 6]. When compared to OST, PDT has the benefit of bedside placement with less complications [5, 7]. Placement of PDT at the bedside requires fewer resources and completely eliminates the need for transport of a critically ill patient and prevents transportation and movement complications [5, 8]. Performing the procedure in the ICU avoids using operating room and also eliminates financial and time expenditure such as room time, turnover, and personnel. This also reduces overall cost [2, 3, 5, 9–12].

The use of ultrasound and flexible bronchoscopy as adjuncts in the performance of the procedure will also be described. We will also review the long-term management of tracheostomy including tracheostomy changes and decannulation and the current recommendations on tracheostomy in patients infected with the novel COVID-19 virus.

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Indications

There is considerable variation in the timing of tracheostomy and optimal patient selection [2]. In general terms, there is consensus that patients should be considered to potentially undergo tracheostomy (open vs. percutaneous) if they remain intubated for 10–14 days or there is anticipation that they will be intubated for a longer period of time [2, 3, 13–15]. There is considerable variation on this timing in the literature. Some populations may benefit from earlier tracheostomy such as traumatic brain injury and stroke [2, 16, 17]. Indications for tracheostomy are listed in Table 8.1 and are generally based on the need for long-term airway protection and/or inability to wean from mechanical ventilation [2].

Contraindications

Absolute Contraindications

There are few "absolute" contraindications to the procedure. Since tracheostomy is essentially an elective procedure, the timing of tracheostomy can be deferred till underlying conditions can be corrected or improved upon [2].

- Emergent airway – surgical cricothyroidotomy indicated
- Active infection at the surgical site
- Operator inexperience

Table 8.1 Indications for tracheostomy

General indications for tracheostomy
Orotracheal intubation >14 days
Inability to wean from mechanical ventilation with an endotracheal tube
Improved comfort and mobilization on mechanical ventilation
Management of pulmonary secretions
Inability to safely intubate from an orotracheal route
Inability to ventilate due to neurologic conditions (spinal cord injury, stroke)
Relief of upper airway obstruction (e.g., surgery, trauma, foreign body, tumor, obstructive sleep apnea)

Relative Contraindications

These contraindications depend on operator experience and knowledge and ability to access the airway. Only patients that are medically stable should undergo this procedure.

- Anatomic abnormalities of the neck (e.g., overlying mass, overlying innominate artery, short neck, difficulty in neck hyperextension)
- Morbid obesity
- Unstable cervical spine fracture or ligamentous instability [2, 18, 19]
- Unstable hemodynamics
- Severe gas exchange abnormalities (ventilator dependence with FiO_2 >50% and PEEP >10)
- Uncontrolled coagulation abnormalities
- Children with an immature airway
- Elevated intracranial pressure
- Hemodynamic instability

Risks/Benefits

In considering tracheostomy, there should be a thoughtful discussion with the patient and/or their surrogate decision-maker. Discussions with the patient and surrogate decision-maker in respect to this procedure should take place in the context of goals of care discussions with appropriate documentation [1].

Depending on the patient diagnosis and underlying medical conditions, a tracheostomy can be a therapeutic part of the recovery process. This procedure may prolong life and may even prolong patient suffering [1]. Overall patients requiring tracheostomy have poor outcomes, and it is important that patient care teams work together to place the decision for the procedure within the context of the patient prognosis and patient goals [1].

Risks

Risks of the procedures (PDT and OST) primarily include bleeding (0.1–5%), local soft tissue infection, hypoxia, increased intracranial pressure,

hemodynamic instability, loss of airway, pneumothorax (0.2%), pneumomediastinum, posterior tracheal wall injury (1.6%), esophageal injury, creation of false tract, and the inability to complete procedure. Long-term risks include tracheal stenosis (1.7% overall) [17]. Mortality associated with tracheostomy is very low (0–0.7%) [1, 2]. Complication rates of PDT compare favorably to OST. Rates of infection are reported between 1.5% and 4% in the literature and are usually minor [20–22]. The rate of infection in PT is lower than that of OST. Loss of airway may also inadvertently occur during tracheostomy. This could have catastrophic consequences, especially if reestablishment of the airway fails [20–22]. Tracheostomy, when performed by qualified providers, has low risks, and complications associated with the procedure are often not significant.

Benefits

Overall benefits to a tracheostomy for most critically ill patients are centered on helping to facilitate comfort and begin long-term ventilatory management of the patient (Table 8.2) [2, 3, 5].

Preparation

OST and PDT

Laboratory and Medication Considerations

- Standard preoperative labs such as complete blood count and basic metabolic panel. Consider coagulation panel if bleeding or abnormal coagulation profile is suspected.
- Hold any enteral feeding for at least 6 hours prior to the procedure as this is an airway procedure and aspiration is a risk.
- Timing of holding therapeutic anticoagulation treatment should be discussed between the operative team and the treatment team. In some clinical situations where anticoagulation cannot be safely held, consideration for surgical procedure may be required.
- Hold any deep venous thromboprophylaxis the morning of the procedure.

Table 8.2 Benefits of tracheostomy

Improve patient comfort
Improve weaning from mechanical ventilation
Facilitate airway suctioning and secretion management
Expedite patient mobility
Progress care and transfer out of ICU to step down unit, subacute rehab, or long-term acute care facilities
Reduce chances of additional laryngeal, tracheal, and oral mucosa injury from oral endotracheal intubation
Facilitate oral nutrition
Facilitate return of speech

Sedation and Analgesia

In the ICU setting, medications should be considered that would allow at appropriate sedation to a range where the patient is unarousable and has no response to voice or physical stimulation. Once sedation is achieved, add a long-acting paralytic such as vecuronium, rocuronium, or cisatracurium to prevent unwanted patient movement or coughing. Amnestic agents should be liberally dosed to prevent operative recall and to assure adequate sedation. Depending on patient stability, propofol, midazolam, or lorazepam should be considered and used. Analgesic medication should also be used to facilitate pain control and comfort and help achieve the appropriate analgesia and sedation goal. Short-acting analgesic such as fentanyl followed by longer-acting medication such as hydromorphone can facilitate a safe hemodynamic profile while maximizing patient comfort. In the operative setting, the anesthesia team will provide sedation, and this may include general anesthetic for select patients.

Monitoring

Continuous monitoring in either setting (ICU or operating room) is essential and should consist of telemetry, oxygen saturation, heart rate, and blood pressure monitoring. If there is no established arterial blood pressure monitoring, then cycling the noninvasive blood pressure frequency to every 1–3 minutes is recommended. Additionally, end-tidal carbon dioxide monitoring is essential in determining ventilation during

the procedure. Audible oxygen saturation and telemetry settings should be used to provide multiple layers of alerting providers when hypoxia or bradycardia occurs. If either of these situations occurs, the procedure should be paused, and the patient should be appropriately oxygenated and ventilated and reexamined for other causes. If a bronchoscope is in place, remove the bronchoscope to help facilitate ventilation and oxygenation. Medications and fluids to support hypotension should be immediately available.

Additional Team Members

Procedures at the bedside in the ICU should involve a multidisciplinary team approach. The team should include at least two proceduralists, one dedicated to airway and bronchoscope control and the other performing the procedure. The operator should have an assistant (this may be an advanced practice provider (PA or NP), resident, or surgical technician). A respiratory therapist should be dedicated to the procedure to help manage the ventilator and assist in airway and tube manipulation as well as ventilator management. There should be a dedicated nurse administering medications and assisting in monitoring the hemodynamics.

Positioning, Skin Preparation, and Additional Bedside Equipment

The patient should be positioned in the supine position with full neck and upper chest exposed. A shoulder roll is often placed to the interscapular region to push the shoulders forward and allow maximum extension of the neck (Fig. 8.1). This may not be possible in some clinical settings such as cervical spine injury with collar in place or in patients with surgical fixation of the spine. In patients that require inline cervical collar spine stabilization, the use of sandbags, tape, and an assistant holding inline stabilization may be needed. Sterile chlorhexidine-based prep solution is used to provide cleansing of the skin and provide the sterile environment. If there is an allergy to chlorhexidine, then standard Betadine prep may be used as an alternative. Providers should have appropriate personal protective equipment (caps, masks, eye protection).

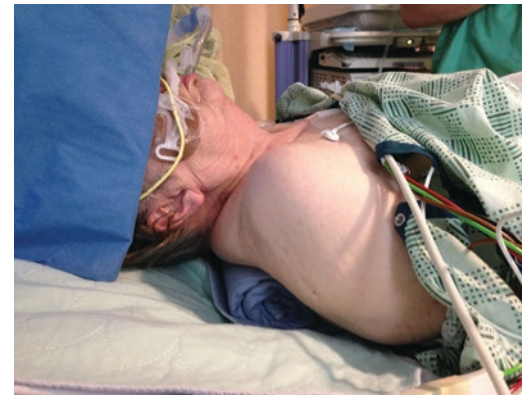

Fig. 8.1 Patient positioned in bed with towel roll under scapula. (Courtesy of Peter Sandor)

Operator should have sterile gowns and gloves in addition to other appropriate personal protective equipment. Additional PPE may be required for patients infected with COVID-19.

A rolling bedside table or Mayo stand that elevates above bed height should be available to stage the kit and necessary equipment for bedside procedures. Adequate lighting should be available in the form of overhead procedural lighting that should be available in the ICU. Headlamps should be available if there is inadequate lighting. For OST, Bovie cautery may need to be available for operative bleeding. This should be used only for bleeding outside of the trachea and prior to entry to the trachea. The risk for operative fire increases after into the trachea as the availability of an oxygen-rich and flammable mixture increases. For PDT procedures, sutures (4-0 or 6-0 absorbable suture on taper needle) should be available for ligation of bleeding vessels if needed. Suction should be available for the operative provider and another suction set for the bronchoscopist.

Emergent airway carts and emergent airway surgical trays should be available within the patient room or in situations with isolation precautions – immediately available outside the room. A surgical trach tray should be used in the open tracheostomy. This should have tracheal dilators, trach hooks, and appropriately sized scalpels and scissors available. Ideally, this is predetermined well in advance of any procedural

task. For PDT in the ICU, the emergent surgical tray should be immediately available to the team.

Bedside PDT Kits

There are many commercially available PDT kits available. Some of the most readily available and used kits include the Ciaglia Blue Rhino® Advanced Percutaneous Tracheostomy Set, the Griggs Percutaneous Dilation Kit®, and the Blue Dolphin Kit®.

Bronchoscope

The bronchoscope has many advantages in the performance of this procedure (Fig. 8.2). If used appropriately sized scopes to facilitate evaluation of the airway should be available. The bronchoscope is used to visualize the inner airways, clear and copious secretions pre-procedure. It is used as a bougie to safely withdraw the endotracheal tube into the glottis and can be used to facilitate reintubation if inadvertent extubation occurs. It is useful to assist in the visualization of the correct placement of the introducer needle, guidewire, and the passage of the dilators and the final placement of the tracheostomy tube [2, 5]. This helps prevent creation of false passage, helps avoid posterior wall perforation, and helps assure midline tracheostomy placement. The bronchoscope can be used at the end of the procedure to confirm placement of the tracheostomy in the trachea and to clear blood or mucus from the airways if present.

Fig. 8.2 Example of fiberoptic bronchoscopy tower with surgical airway tray on bottom shelf

Ultrasound

Ultrasound can also be used as an adjunct to both OST and PDT though identification of cervical landmarks and vascular structures. It may also be useful in morbidly obese patients and repeat tracheostomy patient where neck anatomy is difficult to discern [2, 5]. Use of the ultrasound may alter and confirm the placement of the initial puncture of the trachea and ensure avoidance of the anterior jugular veins, thyroid arteries and a high-riding tracheoinnominate artery. In traumatic brain-injured patients, use of ultrasound for tube evaluation and positioning may mitigate increases in intracranial pressure and rising carbon dioxide levels that may be seen with bronchoscopy during the procedure [2, 5]. Sterile probe covers will be required if this is use during the procedure (V).

Procedure

Percutaneous Dilatational Tracheostomy (PDT)

Follow the steps listed above in regard to sterile personal protective equipment. Perform appropriate surgical time-out in accordance with hospital policy or guidelines. This may include patient identification, consent signed and present in the room, appropriate personnel and antibiotic plan if needed, reviewing risk of operative fire, and identifying personnel and their roles. Prepping and draping of the patient neck can occur as part of the procedural setup, and minimum draping requirements are generally limited to the neck region.

We will review the steps and technique for the Cook Critical Care (Bloomington, IN)

Fig. 8.3 Blue Rhino percutaneous tracheostomy set. (Permission for use granted by Cook Medical, Bloomington, Indiana)

Ciaglia Blue Rhino® Advanced Percutaneous Tracheostomy Set (Fig. 8.3). Other sets have similar but distinct techniques.

Preparing the Kit

1. Inspect the kit for integrity and expiration date.
2. Open the kit under sterile condition and place it on the bedside stand.
3. Place appropriate Shiley tubes (#6 or # 8) on the tray in a sterile fashion.
4. With the kit now opened, place sterile water or saline ~50 ml into the empty reservoir tray of the kit. This provides the hydrophilic environment for activation of the Blue Rhino dilators.
5. Remove the inner cannula for the Shiley tracheostomy, and place it in a location where it will be remembered and easily retrieved for insertion.
   - Patient cannot be connected to the ventilator circuit without this attachment in place.
6. Inspect and evaluate the tracheostomy tube integrity by inflating and deflating the cuff.
7. Lubricate the tracheostomy tube with water-soluble lubricant and the corresponding dilator.
8. Place the appropriate self-loading dilator into the distal portion of the tracheostomy tube. The tapered end should protrude approximately 2 cm.
   - The kit contains a 24, 26, and 28 French loading dilators that correspond to a size 4, 6, and 8 Shiley, respectively (Figs. 8.3 and 8.4)
9. Place the thin white guiding catheter into the narrow end of the Blue Rhino tapered dilator to the ridge. Moisten with the sterile water or saline in the tray (Fig. 8.5).
10. Place the items from the kit you are going to use in the order of planned use onto a sterile cover of the bedside table. This allows a stepwise access to all the equipment in an efficient manner.

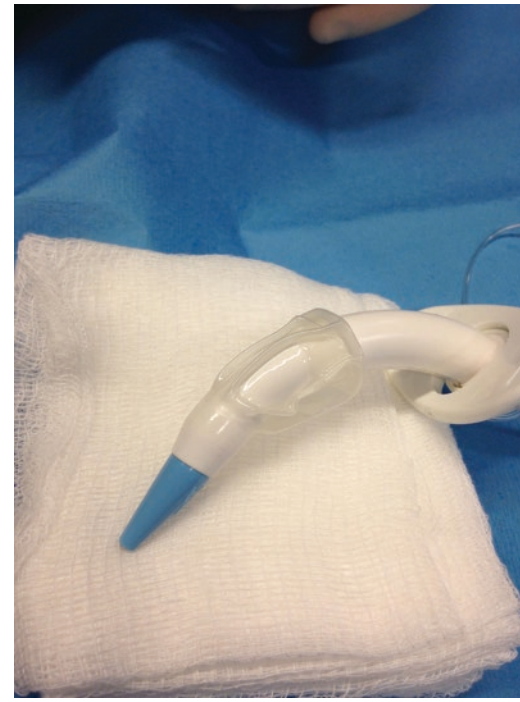

Fig. 8.4 Loaded Shiley tracheostomy tube loaded with dilator. (Courtesy of Peter Sandor)

Final Preparation

Patient should be positioned as described above with hyperflexion to expose the neck and to allow examination of tracheal rings. Operator should reexamine the neck and anatomy when in this position prior to final donning of sterile gown and gloves. Palpate the thyroid cartilage. Move inferiorly and locate the cricothyroid membrane, the cricoid cartilage, and then the first and second

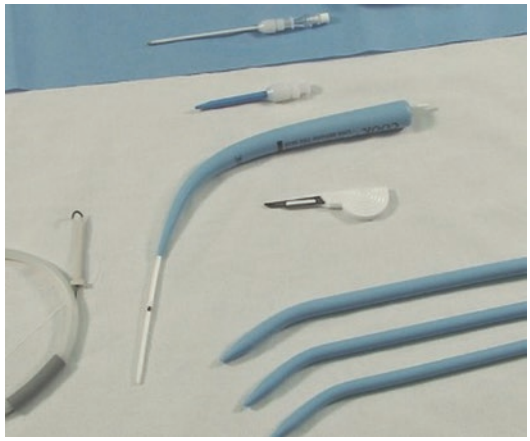

Fig. 8.5 Blue Rhino dilator loaded with the white guide catheter. (Courtesy of Ronald F. Sing)

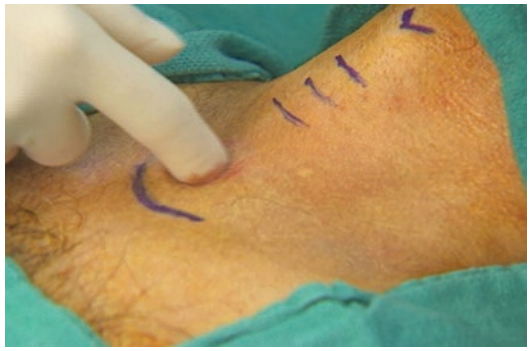

Fig. 8.6 Anatomy of the neck marked prior to procedure. (Courtesy of Ronald F. Sing)

tracheal rings. Ideal location for needle puncture will be either the first or second tracheal ring interspace (Fig. 8.6).

Patient should have the FiO_2 increased to 100% for the duration of the procedure. The bed should be adjusted to accommodate the bronchoscopist and operator. The bronchoscopist should prepare the bronchoscope. Check suction and image quality and use anti-fog on the end of the scope. Have an appropriate dual access bronchoscope adapter placed on the endotracheal tube to minimize leak. Have a water-soluble lubricant available to facilitate bronchoscope insertion into the adapter. Also assure an adequate amount of saline is available for irrigation of the channel if needed for secretions.

Prep the patient's neck with chlorhexidine solution and allow to dry. Place the sterile drape contained in the kit on the patient with the center of the hole of the drape located over the thyroid cartilage and sternal notch.

ODT Procedure Steps

- Step 1: Reassess the appropriate landmarks and the second tracheal space.
- Step 2: The bronchoscopist should perform an initial evaluation into the endotracheal tube and the tracheobronchial tree to assure there is no significant mucus or secretions and to assess the anatomy of the trachea.
- Step 3: Withdraw the bronchoscope into the tip of the endotracheal tube. This provides bronchoscope access into the endotracheal tube without significantly compromising delivery of oxygen and gas exchange.
- Step 4: Use a 10 ml syringe filled with 1% lidocaine with epinephrine, and infiltrate the skin and subcutaneous tissue via the 25-gauge needle.

Alternative Step

Some operators at this time will make a skin insertion incision of ~1 cm in a vertical fashion and will use blunt dissection to open up the subcutaneous and pretracheal fascial space (Fig. 8.7a–c).

- Step 5: When ready, the bronchoscopist should begin the process for withdrawing the endotracheal tube above the puncture site. This part of the procedure needs coordination and closed-loop communication to reduce the risk of inadvertent extubation.
- Step 6: The respiratory therapist should then unsecure the endotracheal tube but still maintain full control of the tube with their hand. The bronchoscope is then advanced forward to the level of the carina.
  - The purpose of this maneuverer is for the bronchoscope to act as a "bougie" in case there is inadvertent extubation. This will

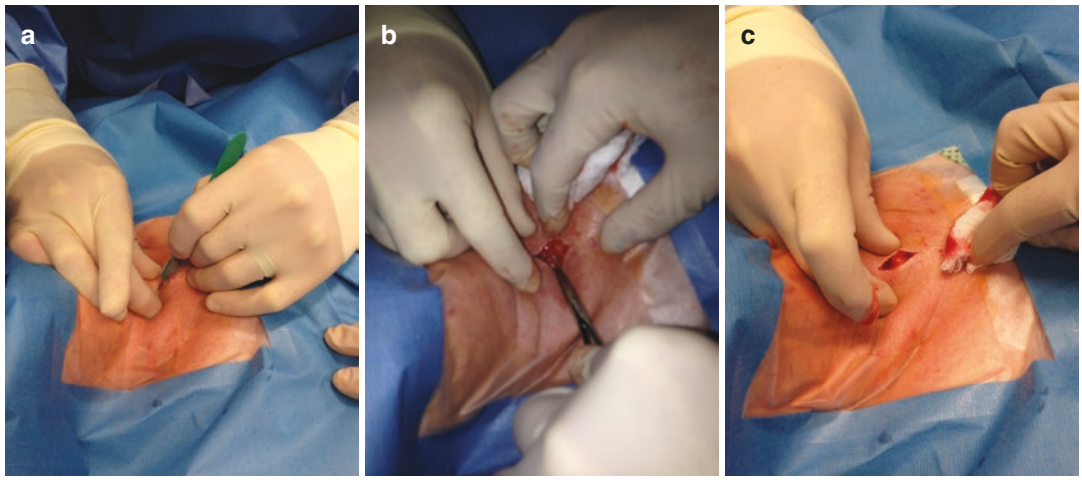

Fig. 8.7 (**a**): Beginning of skin incision, (**b**) blunt dissection to the pretracheal fascia, (**c**) final opening. (Courtesy of Peter Sandor)

help facilitate reintubation over the bronchoscope if withdrawn too far out.

- Step 7: With the bronchoscope at the carina, the bronchoscopist or respiratory therapist withdraws the endotracheal tube slowly and methodically to approximately 18 cm mark at the patient lip. The numbers on the endotracheal tube should be communicated aloud to the operating surgeon to facilitate closed-loop communication, thereby possibly preventing inadvertent extubation.
  - The 18 cm mark should place the endotracheal tube just below the glottis.
  - The operator should have their hand on the neck at the planned insertion site at all times. The operator should be able to feel the tube sliding under their finger, and then "drop" occurs when the tube retracts to a position above the planned tracheal puncture site.
  - Transillumination through the tracheal wall can often help to determine the reasonable distance of withdrawal of the ET tube as well (Fig. 8.8).
- Step 8: Obtain the 15-gauge introducer needle with the soft white introducer sheath. Use a 10 ml syringe filled with ~3 ml of sterile saline or water and place it on the introducer needle.
  - The fluid aids in confirming entry into the tracheal lumen. When the needle is placed and aspirated in the airway, there are usually bubbles noted within the syringe (Fig. 8.9).

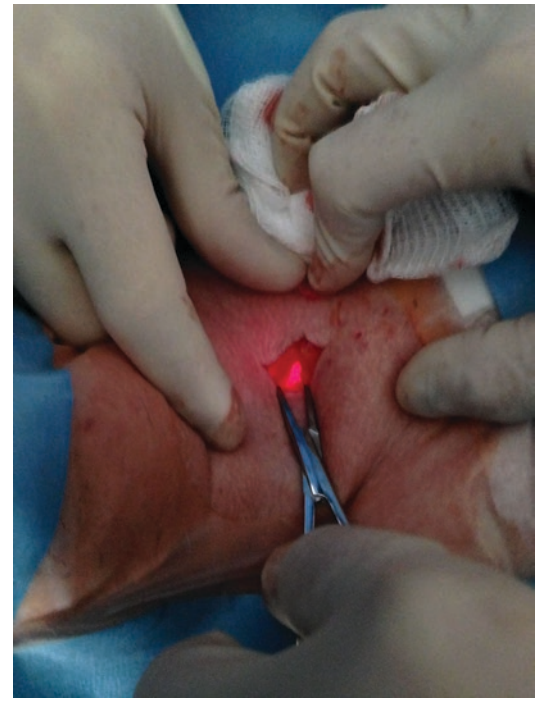

Fig. 8.8 Transillumination from the bronchoscope through the trachea visible to the operators. (Courtesy of Peter Sandor)

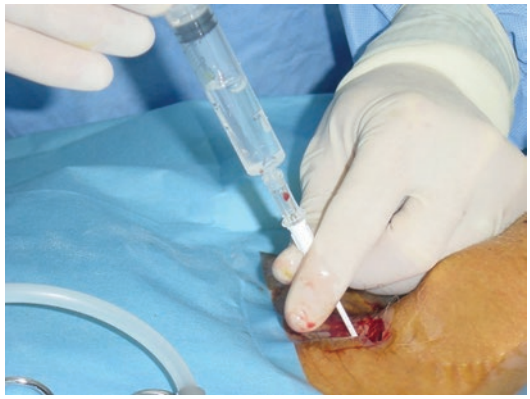

Fig. 8.9 Use of the introducer catheter with introducer sheath. Note aspiration of air on entry to the trachea. (Courtesy of Ronald F. Sing)

- *An alternative step/method is to use the 14-gauge introducer needle in place of the introducer sheath.*
- Step 9: With your nondominant hand, firmly hold the trachea in the midline. Use your thumb and middle finger to secure the trachea from moving. Use your pointer finger pressing onto the midline trachea. This helps to stabilize the trachea and help guide the needle. Use your dominant hand to hold the introducer needle with the syringe, and direct the needle tip into the midline of the tracheal wall under direct visualization from the bronchoscope (Fig. 8.9).
  - Both the bronchoscopist and operator should be able to confirm placement of the needle into the tracheal lumen, and see directly that it was placed midline and that there was no compromise of the posterior tracheal wall.
- Step 10: Once the needle is sufficiently placed in the trachea, remove the needle while advancing the sheath. Leave the white sheath in place while maintaining control of the catheter (Fig. 8.10).
- Step 11: Insert the J-wire into the sheath and aim caudally (Fig. 8.11).
- Step 12: Feed the wire into the trachea, and confirm via the bronchoscope whether the wire is passing down toward the carina (Fig. 8.12).

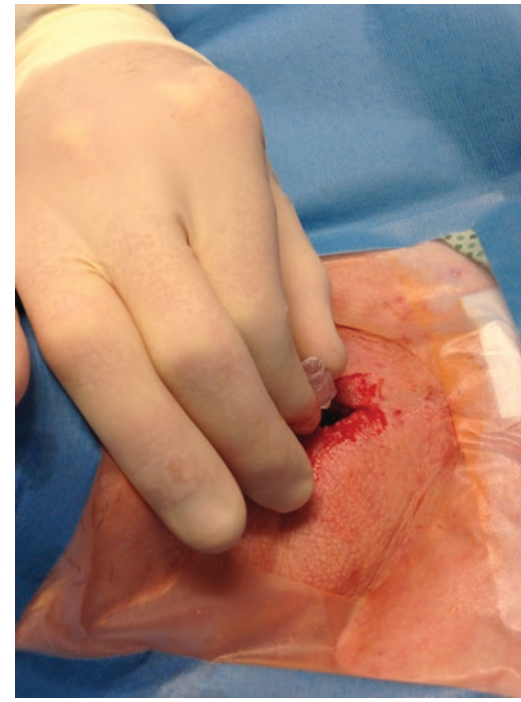

Fig. 8.10 Needle in position in the trachea. (Courtesy of Peter Sandor)

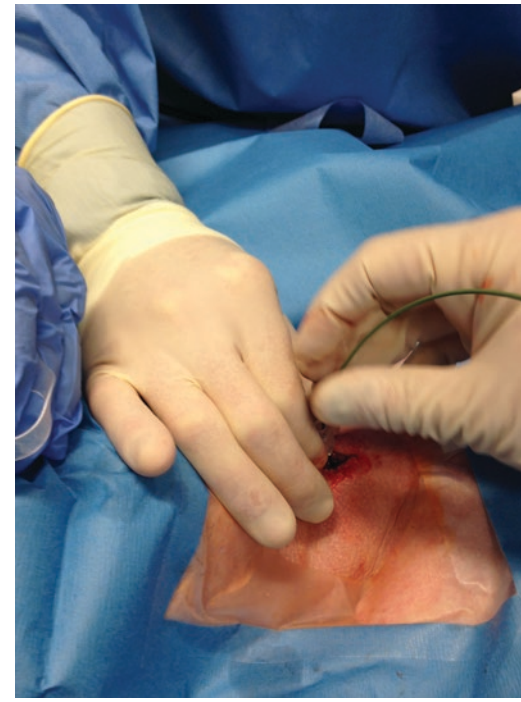

Fig. 8.11 J-wire being advanced into the trachea. (Courtesy of Peter Sandor)

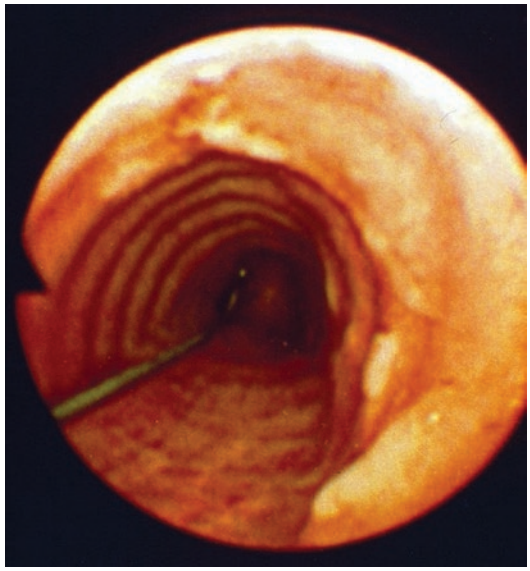

Fig. 8.12 Confirmation of J-wire in following path to the carina as seen from the bronchoscope. (Courtesy of Ronald F. Sing)

- Step 13: Once the wire is at the carina, withdraw the sheath over the J-wire while preventing wire migration. Maintain firm control of the wire. The wire should be essentially maintained and fixed in place by the operator.
- Step 14: Place the blue 14-Fr. introducer dilator over the wire, and advance through the puncture site about three times while performing a twisting or corkscrew motion. Then remove the blue introducer over the wire (Fig. 8.13).
- Step 15: Insert the large dilator that was preloaded with the white guiding catheter over the guidewire (Fig. 8.5). Hold the white guiding catheter at the back end to keep the safety ridge at the tip of the large dilator. Note the black line on the side of the dilator that indicates where the dilator should be placed at skin level.
- Step 16: Pass the large dilator with the white guiding catheter into the tracheal lumen at a 90-degree angle. Pass the dilator repeatedly to the black line at the skin at least one to three times to assure appropriate dilation of the tract (Figs. 8.14, 8.15, and 8.16).

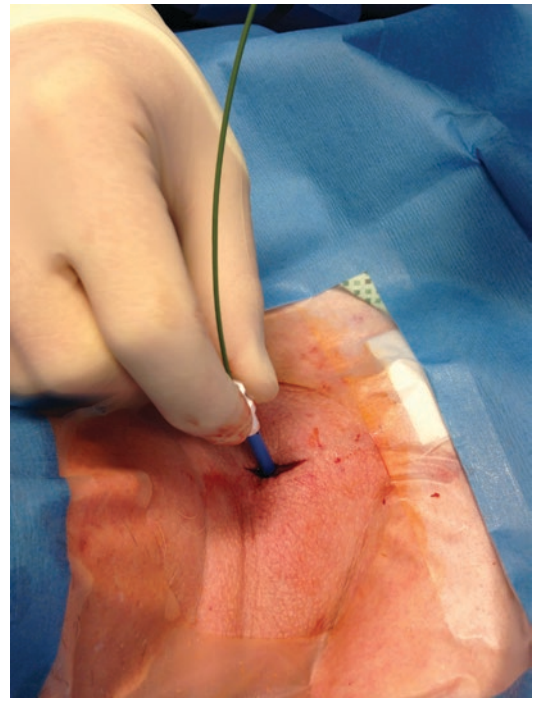

Fig. 8.13 Introducer dilator advanced over the wire into the trachea. (Courtesy of Peter Sandor)

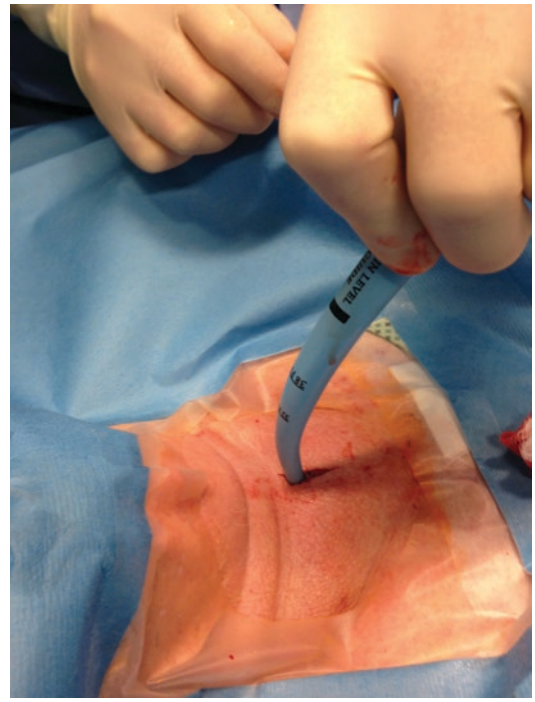

Fig. 8.14 Large dilator at a 90-degree angle to the skin. Preparing to be advanced. (Courtesy of Peter Sandor)

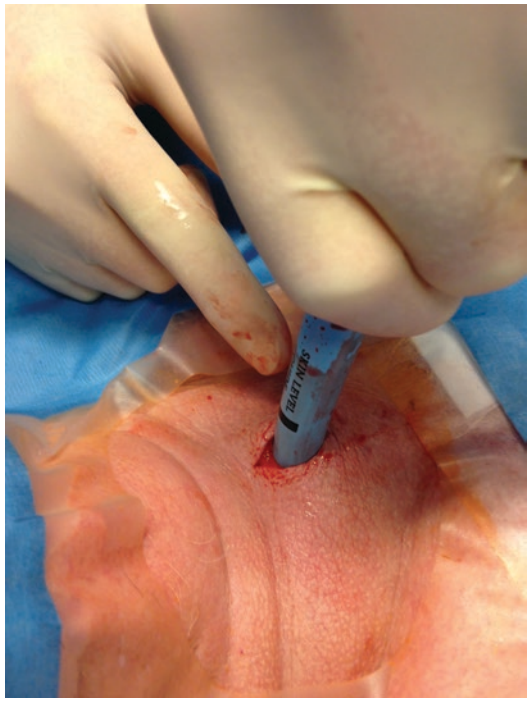

Fig. 8.15 Large dilator being advanced into the trachea to the skin level – large black line. (Courtesy of Peter Sandor)

- Step 17: Remove the large dilator, leaving the white guiding catheter and the guidewire in place.
- Step 18: Advance the tracheostomy tube with the blue loading dilator as one unit over the wire and white guiding catheter. Make sure the safety ridge abuts the tip of the loading dilator.
- Step 19: Advance tracheostomy and the components as a unit into the trachea at the same 90-degree angle (Figs. 8.17 and 8.18). Use gentle but firm pressure. Allow the curve of the tracheostomy to advance in a natural fashion when you are through the opening. Use caution to not exert too much pressure as this may lead to the wire bending and possibly creating a false path. Expect resistance when the deflated cuff is advanced through the anterior tracheal wall. This will be followed by a complete loss of resistance as the cuff passes through.
- Step 20: Hold the tracheostomy in place once it is seated and then withdraw the loading dilator, wire, and guide sheath as a unit. The operator must maintain control of the tracheostomy tube until properly secured (Fig. 8.19).
- Step 21: Insert the inner cannula that was set aside at the beginning (Fig. 8.20).
- Step 22: Inflate the balloon on the tracheostomy tube.
- Step 23: Withdraw the bronchoscope from the endotracheal tube, and insert the bronchoscope into the tracheostomy tube to confirm correct placement of the tracheostomy in the trachea and to assess for bleeding and secretions.
- Step 24: Attach the ventilator to the tracheostomy tube and monitor end-tidal CO_2 and oxygen status and assure appropriate ventilator function and waveforms.
- Step 25: Secure the tracheostomy tube with tracheostomy straps or another approved device (Fig. 8.21).
  - Suturing the device to the skin should be avoided as it does not prevent tracheostomy dislodgement and may result in pressure-related skin issues and ulceration [17].
  - Chest radiography is not required unless complications or concerns arise.

Once confirmation of appropriate placement has occurred, then the endotracheal tube may be removed.

Tube dislodgement is a serious event and is mitigated through vigilance by the nursing and respiratory therapy staff. Prevention of torque on the tracheostomy tube by having secured ventilator tubing, proper patient turning, and attention to the tube as well as good trach tube positional maintenance will help to prevent dislodgement.

The final step is securing all sharps and disposing of them in appropriate containers as well as cleaning up after the procedure and cleaning the patient as needed.

Open Surgical Tracheostomy (OST)

Assure the team has appropriate sterile dressing and others in the room are protected with appropriate universal precautions (hat, mask gloves, and eyewear).

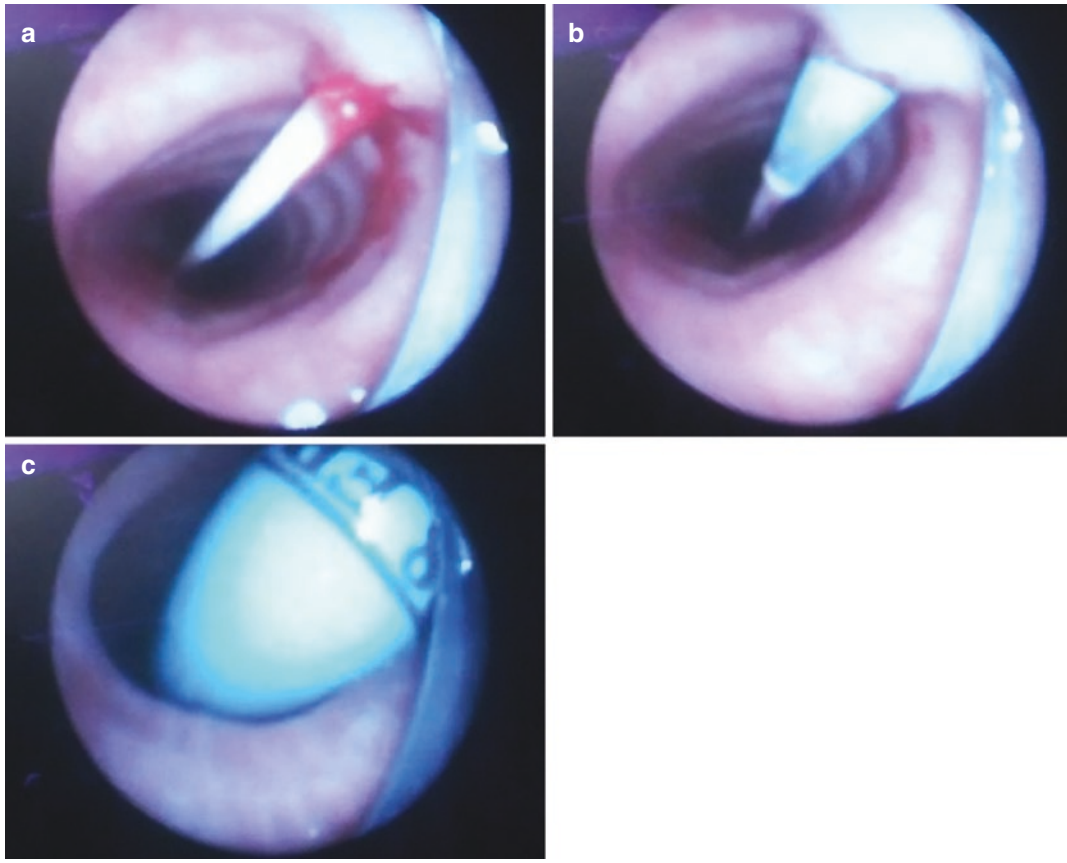

Fig. 8.16 Progression of the guide sheath and the large dilator from the bronchoscopist view in sequence. (**a**) Guide sheath, (**b**) entry of the of large dilator into the trachea, and (**c**) dilator at the 38 French mark

As above, perform appropriate surgical time-out in accordance with hospital policy or guidelines. This may include patient identification, consent signed and present in the room, appropriate personnel and antibiotic plan if needed, reviewing risk of operative fire, and identifying personnel and their roles.

Position and prep the patient as required. This may consist of full body draping for the operative team to maintain a wide sterile field.

Preparation

- Step 1: Have a Shiley #6 or #8 tracheostomy tube available on the field and have the device tested for leak and cuff integrity. Remove the inner cannula and set aside. Load the Shiley with the obturator and moisten with water or saline.
- Step 2: Appropriate surgical trays, instruments and suction available and open.
- Step 3: Identify the thyroid and cricoid cartilages along with the suprasternal notch and the first and second cartilaginous rings. Mark anatomy with sterile marker for landmarks (Fig. 8.6).
- Step 4: Perform a midline or horizontal surgical incision approximately a fingerbreadth below the cricoid cartilage, and dissect down to gain access to the strap muscles. Ensure you are at least 2 cm above the sternal notch.
- Step 5: Once these muscles are encountered, they should be retracted laterally with Army-Navy

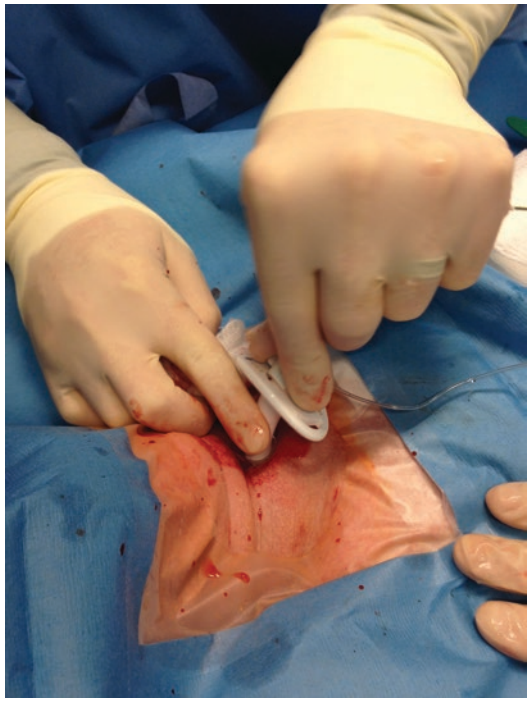

Fig. 8.17 Insertion of the tracheostomy loaded on the dilator into the trachea. (Courtesy of Peter Sandor)

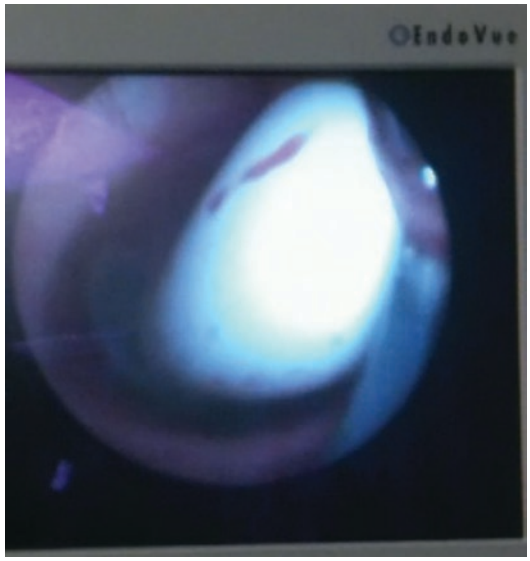

Fig. 8.18 Placement of the tracheostomy in the trachea as seen from the bronchoscope

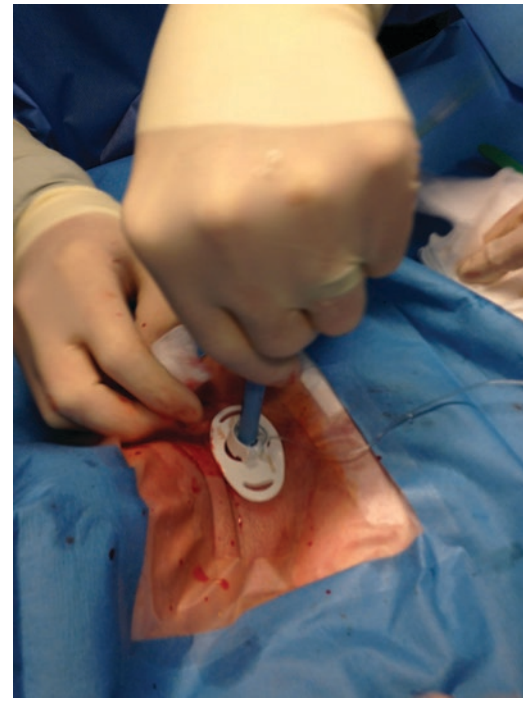

Fig. 8.19 Removal of the dilator, sheath, and wire from the trachea. (Courtesy of Peter Sandor)

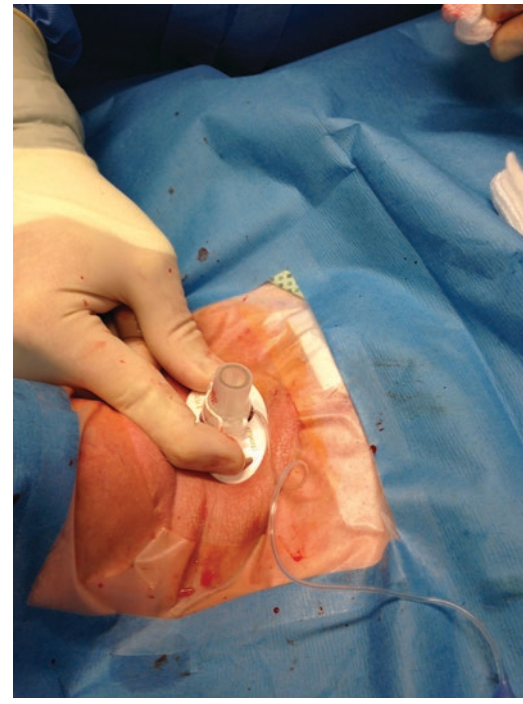

Fig. 8.20 Placement of the inner cannula into the tracheostomy while maintaining control of the tracheostomy. (Courtesy of Peter Sandor)

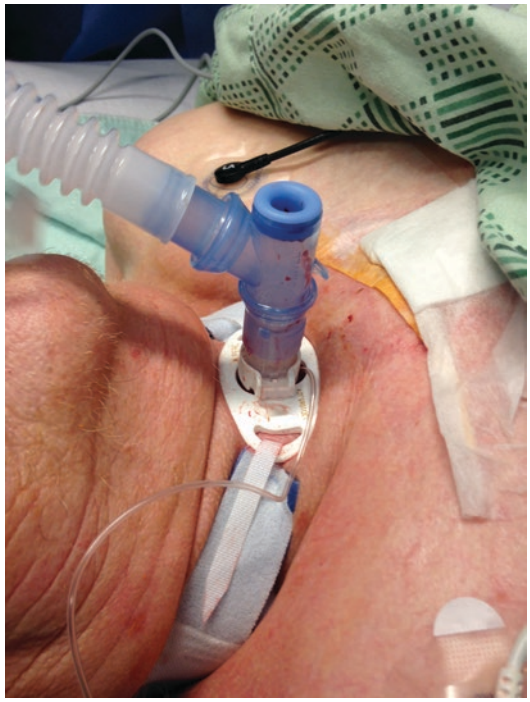

Fig. 8.21 Tracheostomy in place and secured with tracheostomy tube straps. (Courtesy of Peter Sandor)

retractors to permit exposure of the pretracheal fascia.

- Step 6: Use a hemostat or similar instrument to bluntly dissect this tissue.
  - Bovie cautery for any bleeding should be used cautiously, if used at all due to fire risk. It should be noted that the anterior jugular veins, the thyroid isthmus, and thyroidal artery branches may need to be ligated in order to gain access to the second or third cartilaginous rings.
- Step 7: Make an incision on the anterior surface of the trachea using either an inverted U, a rectangular window in the trachea, a sideways H, cruciate incision, or a small excision of the anterior tracheal ring based on operator preference.
  - There is a risk of rupture of the endotracheal tube balloon at this stage. Communication and preparation are key at this time.
- Step 8: Once incision has been made, communicate with the provider managing the airway (anesthesiologist/CRNA if in the operating room or other dedicated provider if in the ICU) to withdraw the endotracheal tube slowly to a level just below the glottis and proximal to the newly created tracheotomy.
- Step 9: Use a tracheal dilator to widen this opening if needed.
- Step 10: Place the tracheostomy tube either a #6 or #8 French Shiley tracheostomy with the obturator loaded into the trachea. The tracheostomy should be placed at a 90-degree angle to the trachea and advanced in a downward manner. And control the tracheostomy until secured.
- Step 11: Remove the obturator and insert the inner cannula and lock.
  - Patient cannot be connected to the ventilator circuit without the inner cannula in place.
- Step 12: Inflate the cuff of the tracheostomy tube.
- Step 13: Connect the ventilator and the CO_2 monitor to the tube to assure adequate ventilation and oxygenation. Assess breath sounds.
- Step 14: Secure the tracheostomy tube using the appropriate collar.

Special Considerations in the Infected COVID-19 Patient

Patients undergoing tracheostomy with infection to COVID-19 may require additional special consideration and steps to prevent aerosolization of viral load.

Patients should be selected that absolutely require ongoing mechanical ventilation.

Recommendations in this population center on minimization of exposure to personnel and aerosolization of the virus. Preforming either PDT or OST in the patients' ICU room minimizes exposure during travel to the OR. Option on bringing the OR team to the ICU when indicated is a safe recommendation. When performing the pro-

cedure, only the minimum number of essential providers should be present in the room. Other required or possibly needed personnel should be outside of the room to support the team. Other aspects of exposure control include appropriate PPE (including powered air-purifying respirator or PAPR or N-95 masks). Procedures should be performed in an appropriate negative flow room as well. Additionally, minimizing aerosolization entails the use of medications to minimize secretions and the use of total intravenous anesthesia and other alternative techniques that prevent disruption of the ventilator circuit [23, 24]. Preventing ventilator disruption may include passing the bronchoscope alongside the endotracheal tube (Fig. 8.22) for direct visualization, placing the ventilator on a "standby" mode prior to the transition of the circuit from the endotracheal tube to the tracheostomy tube and when inserting a bronchoscope [23, 24]. Other providers have created novel negative flow hood [25] for additional procedural protection and modifications to trach collars that prevent aerosolization [25]. The current pandemic continues to evolve, and the implications of these recommendations on patient and provider safety are still not fully known (Table 8.3).

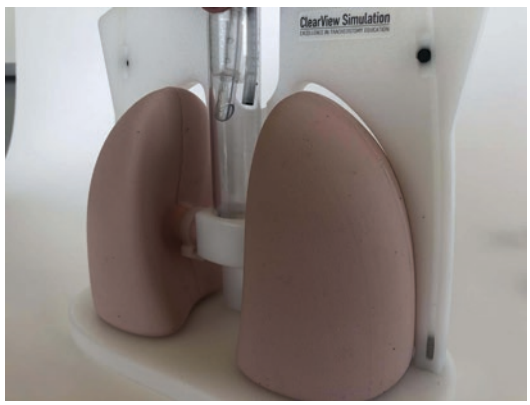

Fig. 8.22 Alternative bronchoscope visualization technique for COVID-19 patients. By passing the bronchoscope lateral to the endotracheal tube cuff rather than through the endotracheal tube, secretions and aerosolization may be minimized and still allows direct visualization of PDT procedures. (Courtesy of Peter Sandor)

Table 8.3 Summary of tracheostomy recommendations for patients with COVID-19 [23, 24]

Recommendations for performing tracheostomy in patients with COVID-19
Experienced proceduralists be available to perform the procedure
Perform in a negative flow room
Use IV glycopyrrolate (0.4 mg) to reduce secretions
Use neuromuscular blockade to prevent coughing
Procedure should be done in a room with negative pressure (ICU or OR)
Use HEPA filter on the ventilator and the suctioning devices
Full impervious draping of patient to minimize contamination on surfaces
If required, use single-use bronchoscopy devices for PDT
Pause ventilator for bronchoscopic evaluation
Pause or place the ventilator on "standby" with placement of the tracheostomy tube to prevent aerosolization
Avoid electrocautery or use smoke evacuator cautery

Tracheostomy Change and Decannulation Procedure

Once a tracheostomy has been placed, providers should institute a plan for tracheostomy change and ultimate decannulation. This process may occur over weeks to several months if and when the patients underlying medical or surgical issues improve and depending on patient dependence on mechanical ventilation. This process generally requires multidisciplinary input from the bedside nurse, speech and language therapy, and respiratory therapy [2, 26, 27].

Patients may undergo the first initial tracheostomy change (downsizing) at approximately 7 days after initial placement if indicated or required. Indications for downsizing are improved clinical status, weaned off mechanical ventilation support (trach collar trials without need for mechanical ventilation >48 hours), or patients that can handle smaller tracheostomy tube with current ventilator settings. Waiting for 7 days until the first change allows the tracheostomy tract to mature and prevent loss of airway.

Tracheostomy changes within the first 96 hours are considered the most dangerous, and guidelines recommend if there is inadvertent decannulation and loss of airway during this timeframe, the patient should be reintubated via the oral route. Attempting reinsertion of the tracheostomy into a fresh stoma during this timeframe may not succeed as the tracheostomy may be introduced into a false passage.

Changing the tracheostomy within the first week is most often related to tube malposition, inability to oxygenate and ventilate with the tracheostomy cannula, cuff leak, or fracture in the cannula. Exchanging the tracheostomy tube during this setting generally requires a multidisciplinary approach and may require revision in the operating room or exchange in the ICU under controlled conditions. Preparation should include establishing airway planning and having backup surgical support immediately available.

Tracheostomy Change

After the tract has been established (7 days or more), tracheostomy change may occur as needed until ultimate decannulation occurs depending on clinical milestones [2]. Patients that no longer have a need for mechanical ventilation and have minimal risk of aspiration and minimal suctioning needs could exchange to cuffless tracheostomy tube when safe to do so. If patients do not require mechanical ventilation and are at high for aspiration or require frequent suctioning or are at high risk for ongoing mechanical ventilation, then downsizing to a smaller cuffed inner cannula is safer.

Tracheostomy Change

- Use appropriate PPE (eye protection, face mask, and gloves).
- Consider suctioning of airway prior to decannulation if needed.
- Have supplemental oxygen available if needed.
- Have appropriate personnel (nursing, respiratory, speech therapy) aware of the procedure to facilitate post-procedure monitoring and care.
- Have the appropriate size(s) of tracheostomy tubes available at the bedside.

Prepare the New Tracheostomy Device

- For exchanges with a cuffed tube, have a 10–12 ml syringe available for deflation.
- Test the balloon for leak and proper inflation.
- When deflating the balloon, make sure the balloon is flat and flush to make insertion easy.
- Make sure the inner cannula is removed.
- Insert the obturator.
- Use either water or water-based lubricant on the tip of the cannula to facilitate insertion.

1. If the patient's current tracheostomy tube is a cuffed tube, assure adequate deflation of the cuff. This entails inflating cuff and deflating to assure all air has been removed.
2. Remove straps or securing devices and assure all sutures have been removed. Remove/set aside trach collar oxygenation to blow as required.
3. Gently pull the device out following the curve of the tracheostomy tube as you remove. May need to rotate the device to 90° laterally to remove in some patients with short necks.
4. After removal, quickly examine the stoma for signs of bleeding, abnormal granulation tissue, and adequate healing.
5. Insert the new device into the stoma with the obturator in place. Begin at a 90-degree angle to the tracheal opening and then follow the natural curve as you insert. Since this is a smaller cannula, it should pass easily. You may need to approach the stoma from a lateral approach and rotate to midline in some instances.
6. Once the device is seated, then remove the obturator and insert the inner cannula while holding the flange in place.

7. If the new tracheostomy is a cuffed tube, then inflate balloon with the appropriate amount of air (~ 10–12 ml).
8. Secure the device with the appropriate straps. They should be snug to the neck.
9. Resume any trach collar oxygen.

Caveats

May have bleeding at the site of removal. Generally self-limited.

Coughing expected with decannulation and reinsertion. Self-limited with airway manipulation.

Decannulation

Ultimate removal of the tracheostomy should occur when the patient no longer needs the tracheostomy or no longer desires its presence (comfort care/palliative situations).

Tracheostomy Decannulation

- Use appropriate PPE (eye protection, face mask, and gloves).
- Consider suctioning of airway prior to decannulation if needed.
- Have supplemental oxygen available if needed.
- Have appropriate personnel (nursing, respiratory, speech therapy) aware of the procedure to facilitate post-procedure monitoring and care.
  1. If the tracheostomy tube is a cuffed tube, assure deflation of the cuff. This entails inflating cuff and deflating to assure all air has been removed.
  2. Remove straps or securing devices and assure all sutures have been removed.
  3. Gently pull the device out following the curve of the tracheostomy tube as you remove. May need to turn the device to 90° to remove in some patients with short necks.
  4. After removal, examine the stoma for signs of bleeding, granulation tissue, and adequate healing.
  5. Occlude the tracheostomy stoma with a piece of petroleum impregnated gauze, a small 4 × 4 gauze, and a piece of tape. In patients able to participate in care, placement of an EKG electrode over the stoma hole can help them find and occlude the hole to facilitate communication.

Caveats

May have bleeding at the site of removal. Generally self-limited.

Coughing expected with decannulation and reinsertion. Self-limited with airway manipulation.

Closure of the stoma usually occurs within a week of removal.

Complications

Morbidity and mortality are quite low with tracheostomy overall [22]. Complications can be divided into three overall categories: immediate, early, and late. Immediate is defined as during or immediately after the procedure; early, within the first few days of the procedure; and late, about a week or more after the procedure.

Immediate

Skin bleeding is the most commonly encountered complication after an incision is made. Minor skin bleeding is usually easily controlled with appropriate surgical sutures placed. Placement of the tracheostomy may also tamponade any bleeding. A Bovie cautery may also be used though care must be used when the tracheal wall has been opened and oxygen supply is present. Operative fires or sparks are a possibility in this setting.

Hypoxia due to mucus plug is uncommon but can occur. The bronchoscope within the endo-

tracheal tube can also increase airway resistance leading to difficulties with ventilation and maintaining adequate oxygen saturation. Not establishing the new airway in a timely manner or loss of airway may also lead to hypoxia.

Pneumothorax, subcutaneous emphysema, and pneumomediastinum may occur due to increased airway resistances and the anatomic location of the pleural lining in relation to the trachea as well as from a false passage (Fig. 8.23).

Posterior tracheal perforation and false passage creation may also occur (Fig. 8.23). This can be the result of needle cannulation and/or tracheal dilator passage into the posterior wall of the trachea; at the same time, the pretracheal tissues can be improperly dilated. Use of bronchoscopy and proper technique is advocated to prevent this from happening. Visualization of the tracheostomy tube in the trachea from the endotracheal tube may confirm adequate placement.

Early

Infection may occur as the airways are not a sterile environment. Local tissue can develop cellulitis from the procedure and secretions. Use of stay sutures and suturing the trach flange to the skin may also serve as a nidus for infection. Attention to routine trach care and removal of suture material, if present, in a timely manner are important. The most devastating considerations are those infections that descend and become a mediastinitis.

Tracheal granulation tissue can occur in the presence of an endotracheal tube or a tracheostomy tube. Areas of pressure against the tracheal mucosa will cause this issue. This granulation tissue can then go on to cause tracheal stenosis and airway turbulence. Consultation with an otolaryngologist might be considered in these circumstances.

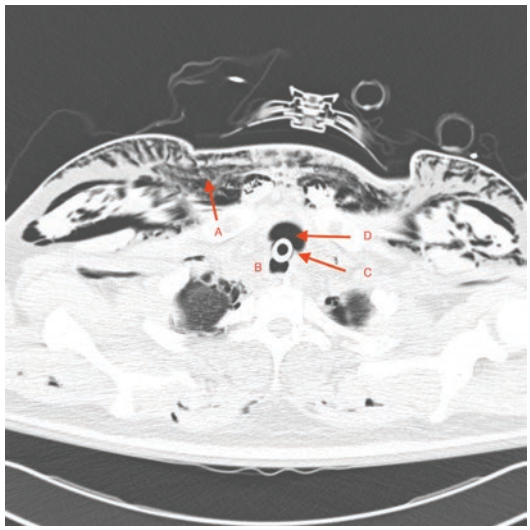

Fig. 8.23 CT demonstrating creation of false passage leading to subcutaneous emphysema. (A) Subcutaneous emphysema, (B) tracheostomy tube partially outside the tracheal space, (C) trachea, (D) air in tracheostomy balloon outside of the tracheal space

Delayed

Significant hemorrhage may also occur in a delayed fashion. The most feared is the tracheoinnominate artery fistula. It is a known but rare late complication of tracheostomy. It should be suspected in patients that have what is called a "herald bleed" from around the tracheostomy described as an initial small bleed prior to a major bleed from the tracheostomy site. Immediate bedside evaluation should occur with consideration for imaging such as a CTA of the chest with the arch vessels. If uncontrolled bleeding occurs, then immediate surgical consultation is warranted.

If severe hemorrhage that does not stop occurs and the patient appears to have immediate hemodynamic changes, immediate exploration in the operating room is warranted. In this setting, the provider may find it helpful to place a finger into the area of bleed and compress the vessel against the sternum. Care should be taken not to injure the vessel further [2, 22, 26].

Inadvertent decannulation may occur during care or inadvertently by the patient. If this occurs within the first 96 hours days post trach placement, it might be quite difficult and dangerous to replace the tracheostomy into the tract. Attempt at replacement may go into a false passage and not be recognized. If there is significant desatu-

ration and hypoxia, oral endotracheal intubation should be performed. Tracheostomy tubes dislodged more than 5 days post placement may be reinserted by an appropriate provider through the stoma by a qualified provider.

Success/Pitfalls/Perils

- Preparation and setup are key in any procedure.
- Prepare equipment in the order of use in a means that you can easily access your equipment.
- Patient selection and appropriate goals of care discussion prevent unneeded or unwanted procedures.
- Closed-loop communication within the team is critical during airway manipulation and movement of the airway device.
- Make sure you have a backup plan for airway management if the tube is inadvertently withdrawn or there is an issue with oxygenation and ventilation.
- Use adequate analgesia and sedation to provide amnesia, and recall especially patients who have been given chemical paralytics.
- Thoroughly evaluate any bleeding from tracheostomy and be vigilant for the dreaded tracheoinnominate fistulae.
- Have patients use a speaking valve (e.g., Passy Muir) as soon as the patient can tolerate even if mechanically ventilated.
- Use a multidisciplinary team approach to the management of the post-tracheostomy patient including nursing, speech and language therapy, and respiratory therapy [2, 5, 27].

CPT Coding

- CPT 31600: Tracheostomy, planned
- This code is used for both open and percutaneous dilatational tracheostomy.
- CMS global period: 0 day [28]

- CPT: 31502. Tracheostomy tube change prior to fistula tract.
- Code is used for tracheostomy tube changes (e.g., balloon rupture or tube dislodgement) prior to epithelialization of the tract (usually by the seventh postoperative day).

- CPT: 31645 Bronchoscopy with therapeutic aspiration
- While fiberoptic bronchoscopy may be helpful with performing PDT, it may not be a billable procedure without sufficient documentation supporting its medical necessity as a separate procedure. In some instances, bronchoscopy can be billed such as when concomitantly performing bronchial alveolar lavage or performing therapeutic clearance of mucus and secretions or blood.

It is most critical that the documentation provided indicates why these procedures were medically necessary [29].

Summary

Tracheostomy is a common procedure in the critically ill and injured patient. With proper patient selection and timing and with the appropriate multidisciplinary team, the procedure is a safe and effective mechanism to facilitate ventilator weaning, improve mobility, and provide patient comfort. Additional benefits of reduced sedation need and progression of care out of the ICU may also be beneficial. Use of PDT and selective OST can improve patient safety and reduce unnecessary cost and patient risks. Multidisciplinary tracheostomy teams that provide ongoing support, tracheostomy changes, and ultimate decannulation are needed to facilitate proper post-tracheostomy care.

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Additional Resources

ClearView Simulation: Tracheostomy training devices and education. http://www.clearviewsim.com/

CMS Physician Fee Schedule: https://www.cms.gov/apps/physician-fee-schedule/overview.aspx

National Tracheostomy Safety Project. National Health System, United Kingdom. http://www.tracheostomy.org.uk

Novel Technique for PDT in COVID-19 patient. https://youtu.be/26ToEI21isE

9 Diagnostic and Therapeutic Bronchoscopy

Jonner Lowe and Jaspal Singh

Introduction

The purpose of this chapter is to provide a basic outline, understanding, and quick reference guide for performing diagnostic and therapeutic flexible bronchoscopy in critically ill patients. We will review patient selection, equipment, and patient preparation. We will also describe procedural technique, anatomy, complications, and troubleshooting tips.

This chapter is primarily intended for an advanced clinical practitioner's (ACP) audience and will focus on using bronchoscopy in intensive care environments. Advanced bronchoscopy techniques such as rigid bronchoscopy, transbronchial biopsy, and other interventional pulmonary procedures are beyond the scope of this chapter.

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Indications/Contraindications

Patient selection for bronchoscopy in the intensive care unit is based on clinical exam, oxygen and ventilation parameters, hemodynamics, and other clinical variables (e.g., coagulation studies during certain diagnostic or therapeutic maneuvers). There are few absolute contraindications to flexible bronchoscopy in mechanically ventilated patients. Caution should be used in patients with severe hypoxemia, unless bronchoscopy is intended to improve the clinical situation, additionally, Caution is also recommended in patients with unstable cardiac rhythms, intracranial hypertension, and severe acidosis (pH < 7.2).

Common Diagnostic Indications for Bronchoalveolar Lavage in Critically Ill Patients

- Recurrent or non-resolving pneumonia.
- Immunocompromised host to rule out opportunistic infection such as *Pneumocystis jirovecii*.
- Infection confined to a lobar segment or airway.
- Determine true infection versus colonization.
- Toxic inhalation or burn injury.

D. A. Taylor et al. (eds.), *Interventional Critical Care*, https://doi.org/10.1007/978-3-030-64661-5_9

Additional Indications Requiring Advanced Bronchoscopic Skill

- Massive hemoptysis
- Centrally located lung mass
- Airway obstruction
- Blunt or penetrating chest trauma
- Bronchopleural fistulas

Therapeutic Indications

- Mucus impaction of the airways with or without lobar collapse.
- Additional therapeutic indications such as performing foreign body removal, tracheobronchial stents, bronchial thermoplasty, treatment of bronchopleural fistulas, cryotherapy, and brachytherapy are beyond the scope of the ACP [1, 7].

Use of Bronchoscopy in Airway Management

In patients with a difficult airway, flexible bronchoscopy can be used for endotracheal tube placement and/or to confirm placement of an endotracheal tube. This may occur as an awake intubation or in an emergent situation where rapid sequence intubation is desired and dual use of a laryngoscope and fiberoptic bronchoscope is needed together to facilitate endotracheal tube placement [2].

Use of Bronchoscopy to Assist with Bedside Tracheostomy

Percutaneous dilational tracheostomy is a common bedside procedure performed in ICUs typically for prolonged mechanical ventilation. Use of a bronchoscope to assist during the procedure provides many advantages such as visualization of each step of the procedure, confirmation of the tracheostomy placement with direct visualization of the carina, reduction of complications, facilitation of team-based care, communication, and education [12].

Risks/Benefits

Bleeding risks for bronchoscopy are minimal for diagnostic purposes when airway inspection, lavage, and/or suctioning is used. Risk of hemorrhage increases with worsening coagulopathy especially when biopsies or other therapeutic maneuvers are used. These should be managed by correcting coagulopathies if feasible prior to therapeutic intervention with practices mirroring other invasive thoracic procedures [3]

Additional relative contraindications include severe thrombocytopenia with a platelet count of less than 30,000 [8]. Antiplatelet medications such as aspirin and Plavix do not need to be held for bronchoalveolar lavage (BAL); however, patient's on direct oral anticoagulants and vitamin K antagonist should be held 24 hours prior to the procedure and/or until the INR is less than 2 [9]. Overall risk of bleeding associated with BAL is relatively low [2, 10].

Anatomy Review

Knowledge of both the upper and lower airway anatomy is essential to effectively perform flexible bronchoscopy safely. The following paragraph is a more detailed description of the lower airway anatomy (see Figs. 9.1 and 9.2 for additional anatomic details):

- The trachea is made up of 16–20 C-shaped cartilaginous rings that are approximately 12 cm in length and 1.6–2 cm in diameter. It terminates at the carina at T4/T5, where it divides into the right and left main bronchus. The right main bronchus is 1–2 mm larger in diameter than the left. It is 25 mm in length and 21 mm in diameter. The left main bronchus is 50 mm in length and 18 mm in diameter. The right main bronchus becomes the bronchus intermedius immediately distal to

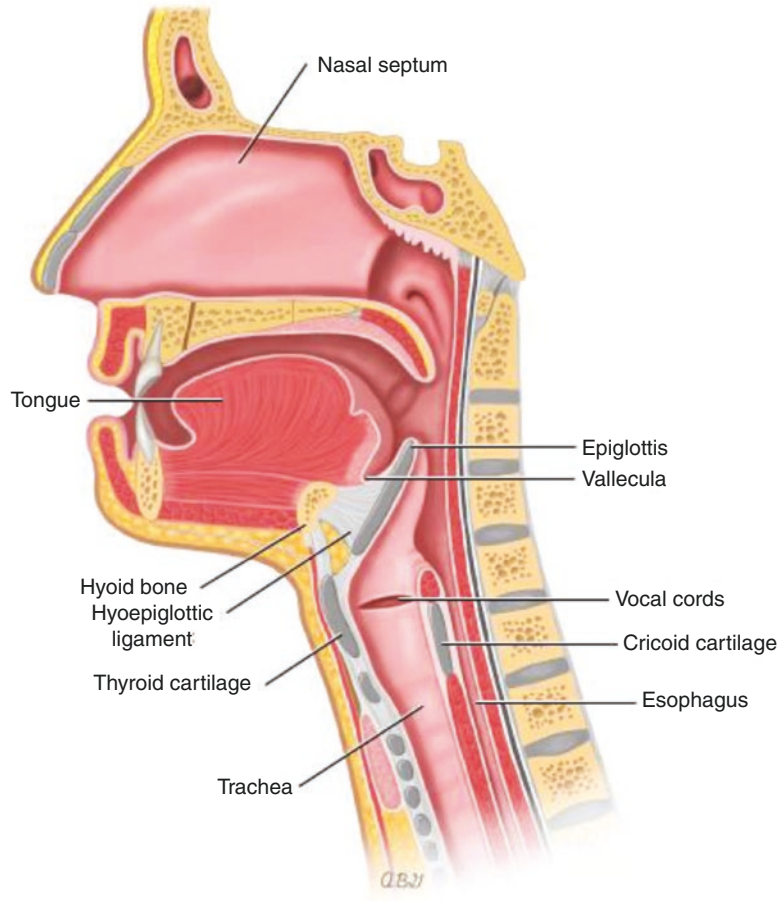

Fig. 9.1 Midsagittal view of the airway. (Reproduced with permission from: Nagler J. Emergency endotracheal intubation in children. In: UpToDate, Post TW (Ed), UpToDate, Waltham. (Accessed on [Date].) Copyright © 2020 UpToDate, Inc. For more information visit www.uptodate.com)

the right upper lobe take off. The bronchus intermedius is 30 mm in length. There are three lobes of the right lung (upper, middle, lower) and two lobes of the left lung (upper with lingula, lower) [13].

Equipment and Patient Preparation

Two main types of flexible bronchoscopes used in the ICUs are disposable and non-disposable (see Fig. 9.3 for basic design). There are advantages and disadvantages to both, most notably the 0% chance of cross contamination with disposable scopes. Once your scope of choice is selected, following a preprinted checklist to ensure proper setup and patient preparation is vital to the success of the procedure and outcome. See bulleted checklist below as a step-by-step guide to performing bronchoscopy. In addition, see below pictures for segmental anatomy (Fig. 9.4).

1. Prior to Starting
   - Coagulation studies checked?
   - CT or chest x-ray reviewed?
   - Are spinal precautions required?
   - All team members are identified and introduced by roles.
   - Procedure timeout.
   - Patient identified correctly.
   - Consent completed.
   - Drug allergies reviewed.
   - Anticipation for possible unique concerns (High FiO_2, PEEP, ICP, coagulopathy).
   - Infection control measures (if suspected TB).
   - Does anyone have any concerns or questions?

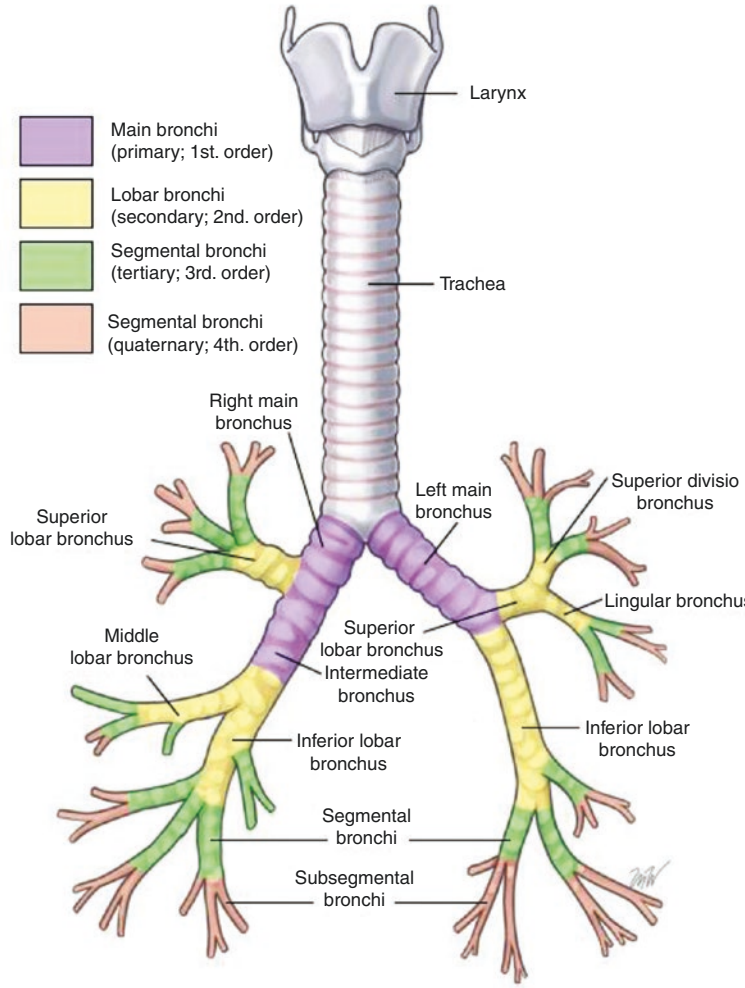

Fig. 9.2 Anatomy of the tracheobronchial tree. (Reproduced with permission from: Islam S. Flexible bronchoscopy in adults: Overview. In: UpToDate, Post TW (Ed), UpToDate, Waltham. (Accessed on [Date].) Copyright © 2020 UpToDate, Inc. For more information visit www.uptodate.com)

2. Prior to Procedure
   - Proper positioning.
   - Check if monitoring is appropriate (cardiac leads, blood pressure monitoring every 5 minutes, oxygen saturation with good waveform).
   - Stop tube feedings and consider removal of gastric feeds.
   - Intravenous access verified.
   - Note endotracheal tube size and ensure the bronchoscope can be accommodated through the tube.
   - Adjust the ventilator to appropriate clinical settings: 100% FiO_2 recommended.
   - Review analgesia and sedation plan. Consider paralytic agent.
   - Check the suction apparatus and ensure proper functioning.
   - 2 mL of 1–4% lidocaine in 2–3 prefilled syringes with air.
   - Prepare 2–3 20 mL slip-tip syringe prefilled with sterile saline for BAL with additional iced saline available if biopsies are intended.

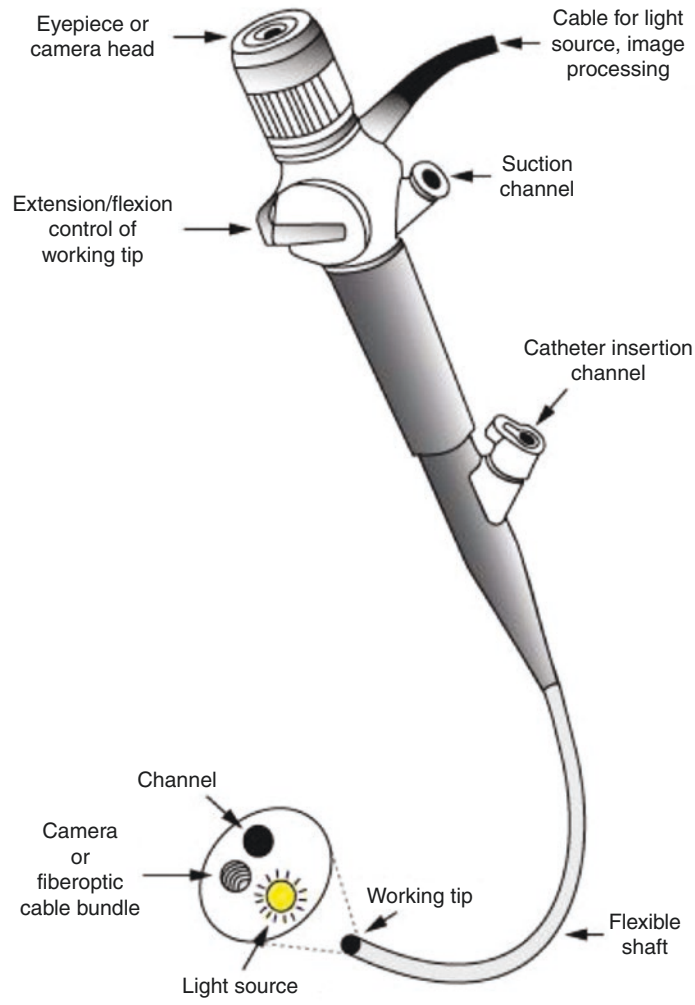

Fig. 9.3 Diagram of a flexible bronchoscope. (Reproduced with permission from: Islam S. Flexible bronchoscopy in adults: overview. In: UpToDate, Post TW (Ed), UpToDate, Waltham, MA. (Accessed on [Date].) Copyright © 2020 UpToDate, Inc. For more information visit www.uptodate.com)

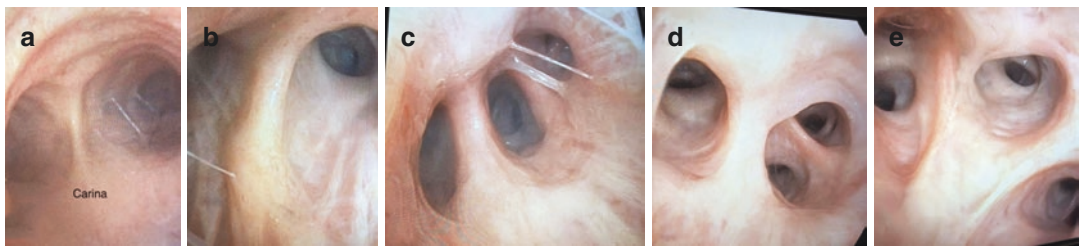

Fig. 9.4 (**a**) Carina; (**b**) Right upper lobe; (**c**) Right middle lobe (far left) and right lower lobe; (**d**) Left upper lobe and lingula (far right); (**e**) Left lower lobe

3. Intra-procedure
   - Lubricate scope with water-based lubricant.
   - Advance scope into ET tube or tracheostomy tube and into the trachea. Visualize the carina, and give 2–10 mL of lidocaine if not paralyzed.
   - Clear large airways of secretions; if infection suspected, culture for washings.
   - If BAL planned after inspection:
     – Advance to terminal bronchi in desired segment and wedge bronchoscope.
     – Attached the sputum trap to the suction valve.
     – Irrigate with 20 mL aliquots × 3–4 or one 60 mL syringe.
   - Remove scope and rinse with suctioning using the enzymatic solution, and wipe scope with antimicrobial sponge
4. Post-procedure
   - Chest x-ray not required unless clinical status changes but might be recommended especially after biopsy of distal parenchyma.
   - Review and/or adjust ventilator settings.
   - Review and/or adjust sedation/analgesia.
   - Complete procedure documentation.

Complications

Overall complications associated with flexible bronchoscopy are low, even when performed on critically ill patients [5, 6]. In one retrospective study on BALs performed in mechanically ventilated ICU patients, incidence of hypoxia and bronchospasm was 9%, with a decrease in the P/F ratio of >25% occurring in 29% of patients [11]. More severe complications such as bleeding and pneumothorax are more likely to occur with additional procedures such as endobronchial and transbronchial biopsies or other advanced procedures [14].

1. Complications
   - Transient hypoxia
   - Bronchospasm
   - Bleeding
   - Hypotension
   - Cardiac arrhythmias
   - Pneumothorax
2. Late Complications
   - Fever
   - Pneumonia

Keys to Success, Perils, and Pitfalls

Often success is built upon good preparation as well as experience of the provider and the entire team. For success, general operating principles of checklist maintenance, team-based care, and team-based training (if able) may be helpful. Additional training is listed below. Caution is warranted in patients with severe medical instability such as shock, severe hypoxemia, coagulopathies, and other high-risk situations. Proper equipment may also not be available at the time needed, so careful attention to the preparation is warranted.

Training/Simulation

Training courses on performing bronchoscopy are limited for ACPs. CHEST offers a yearly bronchoscopy course focused on ICU patients for MDs and ACPs; see link for details (https://www.chestnet.org/Store). Additionally, hospitals with advanced simulation offer excellent training for novice providers and should be a standard for many ACPs prior to performing bronchoscopy in the ICU. On-the-job training is often a main component of learning.

Competence, Certification, and Credentialing

There is limited literature on the qualifications necessary for ACPs to perform bronchoscopy. Competence often comes from established training programs and the number of procedures performed under supervision. Currently, there are no national certification programs for ACPs regarding bronchoscopy. Credentialing is often facility specific and may include proctoring of anywhere between 10 and 35 procedures within a 1–2-year

Table 9.1 CPT coding

31622	Bronchoscopy, rigid or flexible, including fluoroscopic guidance, when performed; diagnostic, with cell washing, when performed (separate procedure)
31624	Bronchoscopy, rigid or flexible, including fluoroscopic guidance, when performed; with BAL
31645	Bronchoscopy, rigid or flexible, including fluoroscopic guidance, when performed; with therapeutic aspiration of the tracheobronchial tree, initial
31646	Bronchoscopy, rigid or flexible, including fluoroscopic guidance, when performed; with therapeutic aspiration of the tracheobronchial tree, subsequent, same hospital stay

Based on data from [15]

period. A consensus statement from a CHEST article by Ernst et al. on adult bronchoscopy training recommends moving away from volume-based (number of procedures performed) certification to a more comprehensive approach that incorporates simulation training, knowledge-based competency assessment, quality and process improvement, and regular assessment of skill maintenance [4].

CPT Coding and Documentation

Most providers document through a templated procedure note. Careful attention should be paid to clearly document the abnormal airway findings and sampling techniques, with a focus on the laterality, target lob, and type of specimen taken [15]. Current procedural terminology (CPT) is often confusing. See Table 9.1 for a list of common CPT codes used for bronchoscopy.

Summary

Bronchoscopy is a useful diagnostic tool for critically ill patients with respiratory failure who are immunocompromised or are failing to respond to conventional treatment modalities. Bronchoscopy also provides therapeutic purposes, mostly in the form of mucus clearance for intubated and tracheostomy patients. Use of bronchoscopy as an adjunct for difficult intubations and bedside tracheostomy provides additional safety during those procedures and contributes to success. We recommend thorough training and simulation with bronchoscopy as well as structured proctoring to become competent and proficient at performing the procedure independently as an ACP. Use of a bedside checklist to ensure patient safety and key steps are followed is important. As with all critical care skills and procedures, knowing one's limitations and working interdependently with the ICU team will ultimately contribute to success.

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Additional Resources

Hands on course provided by CHEST for in depth training for all providers including ACPs, MDs, RNs, RTs. https://www.chestnet.org/Education/Advanced-Clinical-Training/Certificate-of-Completion-Program/Bronchoscopy

British Thoracic Society Guidelines of Flexible Bronchoscopy in Adults https://thorax.bmj.com/content/68/Suppl_1/i1.long

There are multiple online bronchoscopy simulator programs, as well as, hands on simulators that are very beneficial. YouTube also has good videos

Book titled “Introduction to Bronchoscopy” 2nd Edition. Edited by Armin Ernst and Flex J.F. Herth

Part III

Vascular Access Procedures

10 REBOA (Resuscitative Endovascular Balloon Occlusion of the Aorta) Catheter

Dennis A. Taylor, Preston R. Miller, and Matthew David Painter

Device Description

The ER-REBOA™ Catheter is a large vessel occlusion catheter. The device consists of an atraumatic distal tip (P-tip®), a compliant occlusion balloon, and a catheter shaft with a built-in central lumen for blood pressure monitoring. The catheter has a unibody design and is not compatible with a guidewire. The catheter contains two lumens which traverse the length of the catheter and connect to extension lines with stopcocks. The balloon lumen is used to inflate and deflate the balloon. The arterial line lumen is used to monitor blood pressure. Radiopaque marker bands are located on the catheter at the balloon to assist with positioning under fluoroscopy. A peel-away sheath is preloaded on the catheter shaft to ease insertion of the catheter's P-tip® into an introducer sheath hemostasis valve [1] (Fig. 10.1).

Anatomy

The aorta is divided into three separate zones for the purposes of REBOA (aortic length varies and is dependent on the individual).

Balloon Landing Zones

- Aortic Zone 1 – Extends from the origin of the left subclavian artery to the celiac artery (approximate vessel diameter – 20 mm for young adult male) [2]
- Aortic Zone 3 – Extends from the lowest renal artery to the aortic bifurcation (approximate vessel diameter – 15 mm for young adult male) [2] (Figs. 10.2 and 10.3)

Indications for Use

The ER-REBOA™ Catheter is intended for temporary occlusion of large vessels and blood pressure monitoring including patients requiring emergency control of hemorrhage [3–5].

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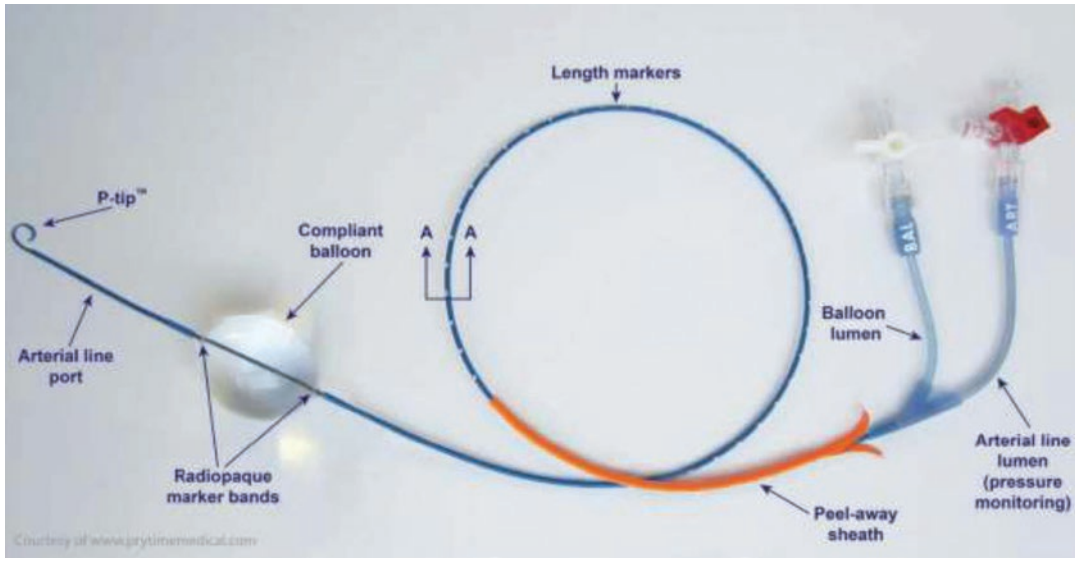

Fig. 10.1 Catheter and balloon example (Prytime Medical ER_REBOA Catheter). REBOA indicates resuscitative endovascular balloon occlusion. (Courtesy of www.prytimemedical.com)

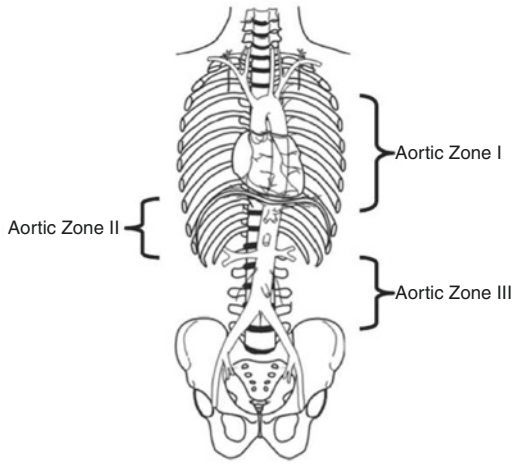

Fig. 10.2 Anatomy. (Courtesy of www.prytimemedical.com)

Contraindications

The ER-REBOA™ Catheter is contraindicated for patients who:

- Have known allergic reactions to contrast media
- Do not have a femoral arterial access site that can accommodate a 7 Fr (minimum) introducer sheath
- Have an aortic diameter larger than 32 mm
- Are minors (younger than 18 years old)

The ER-REBOA™ Catheter is also contraindicated for use with incompatible introducer sheaths. For a list of incompatible introducer sheaths, see the compatibility information below.

Compatibility

The ER-REBOA™ Catheter is intended to be used with a 7 Fr or larger introducer sheath. The ER-REBOA™ Catheter has been confirmed to be compatible with the following 7 Fr introducer sheaths:

- Medtronic Input® Introducer Sheath – 7 Fr
- Cordis Avanti®+ Sheath Introducer – 7 Fr
- Terumo® Pinnacle R/O II Radiopaque Marker Introducer Sheaths – 7 Fr
- Arrow Super Arrow-Flex® Sheath Introducer – 7 Fr

Confirm compatibility with a selected introducer sheath before inserting the introducer sheath into a patient. Compatibility can be confirmed by first sliding the peel-away

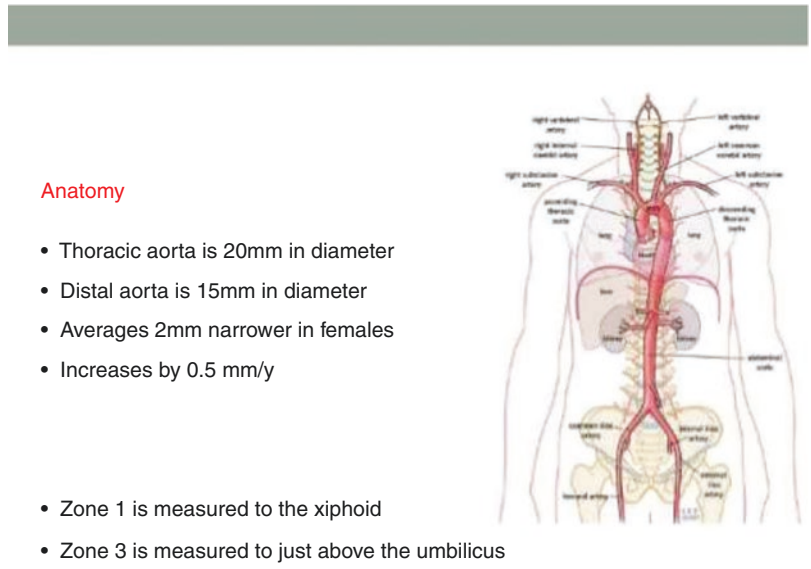

Fig. 10.3 Anatomy. (Courtesy of www.prytimemedical.com)

sheath toward the catheter distal tip to fully enclose and straighten the P-tip® and then inserting the peel-away sheath and catheter into the introducer valve. Once the sheath and catheter enter the valve, advance the catheter through the sheath and introducer about 10 cm. If the catheter can be introduced and advanced through the sheath easily and without significant resistance, compatibility is confirmed. If the peel-away sheath and catheter cannot be introduced to the valve, or advancement of the catheter encounters resistance and requires significant force, the introducer sheath is not compatible.

The ER-REBOA™ Catheter has been confirmed to be incompatible with the following 7 Fr introducer sheaths:

- Arrow AK-09701 Arrow-Flex® Sheath Introducer – 7 Fr
- Cook Check Flo Performer™ Introducer – 7 Fr

Additional introducer sheath models that are confirmed for compatibility or noncompatibility will be updated on the Prytime Medical website at www.prytimemedical.com/product.

Table 10.1 Balloon inflation parameters

Balloon diameter	Inflation volume
9 mm	2 cc
15 mm	5 cc
20 mm	8 cc
25 mm	13 cc
30 mm	20 cc
32 mm (MAX)	24 cc (MAX)

Warnings

- Do not exceed maximum inflation volume. Adhere to the balloon inflation parameters outlined in the Balloon Inflation Parameters Chart (Table 10.1). Overinflation may result in damage to the vessel wall and/or vessel rupture, and/or balloon rupture.
- Hand inflation is recommended. Do not use a pressure inflation device to inflate the balloon. Use of such a device may result in damage to the vessel wall and/or vessel rupture, and/or balloon rupture.
- Do not use a power injector to inject fluid through the arterial line lumen. Damage to the catheter and/or vessel may occur.

- The arterial line lumen must be flushed prior to inserting the catheter into the introducer sheath. Failure to flush the arterial line may result in air embolism and/or poor arterial pressure monitoring. If arterial line lumen becomes occluded, do not force injection or withdrawal of fluids.
- Do not attempt to pass the catheter through an introducer sheath smaller than 7 Fr. Damage to the catheter and/or vessel may occur.
- Do not attempt to insert a guidewire into the catheter. Damage to the catheter and/or vessel may occur.
- The balloon must be flushed prior to inserting into the introducer sheath. Failure to do so may cause an air embolism in the case of balloon rupture.
- Remove all air from the balloon and close the stopcock prior to inserting the catheter into the introducer sheath. Failure to do so may make it difficult to insert/advance the catheter.
- The balloon must be fully deflated with the stopcock closed before removing the catheter. Failure to do so may make it difficult or impossible to remove the catheter from the introducer sheath and/ or vessel.
- Do not use the ER-REBOA™ Catheter for dilation of vascular prostheses. Damage to the vessel and/or balloon rupture may occur.
- Do not use the ER-REBOA™ Catheter as a valvuloplasty/angioplasty balloon catheter.
- The ER-REBOA™ Catheter is supplied sterile and for single use only. Do not reprocess or re-sterilize. Attempting to re-sterilize and/or reuse may increase the risk of patient infection and may compromise the integrity of the device.
- If available, use of conventional x-ray or fluoroscopy is recommended to confirm desired catheter position.
- Note: Length markings on the catheter shaft may be used to measure and track the depth of catheter insertion and desired balloon location
- Use the recommended balloon inflation medium. Do not use air or any gaseous medium to inflate balloon.
- Device is intended for temporary applications. Long-term or permanent application of this device may cause harm.
- The ER-REBOA™ Catheter may be used without the aid of medical imaging. If medical imaging is clinically required in pregnant patients, standard local institutional radiation mitigating measures should be utilized to minimize exposure to the fetus. Once the patient has delivered the baby, the precautions described in this IFU common to all bleeding patients apply.

Precautions

- Prolonged duration of occlusion may result in serious injury or death.
- Do not cut, trim, or modify the catheter or components prior to placement.
- Training and experience in endovascular techniques is recommended for users of this device.
- Balloon rupture may occur under certain anatomical, procedural, and/or clinical circumstances.
- Do not use the catheter for the treatment of dissections.
- Care should be taken when inflating the balloon in the vessel, particularly when inflating in calcified, stenotic, and/or otherwise diseased vessels.
- Carefully inspect the package and catheter prior to use to verify no damage occurred during shipment or storage. Do not use the catheter if the package or catheter is damaged as the sterility or integrity of the device may be compromised and thus increases the risk of patient infection and device malfunction.
- Do not use after labeled expiration date.
- If an obstruction in the vessel prevents or resists advancement of the catheter, do not force catheter past the obstruction. Remove the catheter and use an alternative treatment.
- Do not exceed more than ten inflation/deflation cycles of the balloon.

- The balloon is highly compliant. Inflate the balloon slowly to avoid overinflation.
- Use of contrast media under appropriate medical imaging, i.e., conventional x-ray or fluoroscopy, may be used to confirm balloon inflation.
- Carefully monitor the patient's blood pressure throughout the procedure.
- Preparations should be made, and a trained surgical team should be available in the event that conversion to open surgery is required.

Potential Adverse Events

Possible clinical complications associated with this type of procedure include, but are not limited to, the following [6]:

- Vessel dissection, perforation, rupture, or injury
- Occlusion at some locations may cause arrhythmia
- Paresthesia
- Contrast reactions
- Infection, hematoma, and/or pain at insertion site
- Cardiac events
- Respiratory failure
- Hemorrhage
- Stroke
- Aneurysm rupture
- Renal complications
- Arterial thrombosis and/or embolism
- Paralysis
- Ischemia
- Death

Instructions for Use

Balloon Preparation

Note: The balloon and balloon lumen of the ER-REBOA™ Catheter contain air. Air must be removed from the balloon and balloon lumen prior to insertion using standard techniques [5].

1. Prepare the balloon lumen with inflation medium as follows:
   (a) Attach syringe with appropriate amount of inflation medium and open the stopcock on balloon lumen.
   (b) Purge all air from the balloon using standard techniques.
   (c) Completely deflate the balloon and close the stopcock.
   (d) Disconnect the syringe and purge air from the syringe. Refill the syringe with up to 10 cc of inflation medium and reconnect the syringe.
2. Slide the peel-away sheath toward the catheter distal tip to fully enclose and straighten the P-tip®.
   - Note: The outside of the balloon may be wetted with saline to facilitate advancement of the peel-away sheath over the balloon. The peel-away sheath may also be rotated as it is slid over the balloon.
   - Note: The entire P-tip® should be contained within the peel-away sheath to facilitate insertion into the introducer sheath.

Pressure Monitoring Lumen Preparation

3. Connect the pressure sensor and extension tubing (optimal length 48″ (122 cm) or shorter) using standard techniques to the catheter's arterial line three-way stopcock. Flush the ER-REBOA™ arterial line with saline using standard techniques, readying the device for pressure transduction.
   - Note: The pressure monitoring lumen should only be flushed *after* the peel-away sheath is slid distally to straighten the P-tip®.
   - Note: The pressure monitoring capability of the ER-REBOA™ Catheter is independent of balloon function.

Balloon Introduction and Inflation

4. Insert the peel-away sheath and catheter into the 7 Fr (or larger) introducer sheath approximately 5 mm or until the peel-away sheath hits a stop. Do not advance the peel-away sheath any further. Advance the catheter 10–20 cm into the introducer sheath, and then slide the peel-away sheath toward the catheter hub. If necessary for full advancement, pull tabs to separate the peel-away sheath from the catheter shaft.
   - Note: Do not allow the entire peel-away sheath to enter into the introducer sheath. The peel-away sheath is intended only to temporarily open the valve of the introducer sheath to facilitate introduction of the catheter tip.
5. Using standard technique, advance the catheter to the desired position. If available, use of conventional x-ray or fluoroscopy is recommended to confirm position using radiopaque markers.
   - Note 1: If resistance is encountered when advancing the catheter, do not advance the catheter any further. Withdraw the catheter and pursue alternate treatment.
   - Note 2: Length markings on the catheter shaft may be used to measure and track the depth of catheter insertion and desired balloon location.
6. Refer to the balloon inflation parameters table (Table 10.1) as a guide. Do not exceed maximum inflation volume. Overinflation of the balloon may result in damage to the vessel wall and/or vessel rupture and/or balloon rupture.
7. Carefully inflate the balloon with inflation media. Balloon inflation may be confirmed using contrast media and appropriate medical imaging, i.e., conventional x-ray or fluoroscopy. Monitor the pressure feedback on the syringe plunger while inflating the balloon. Do not force excessive fluid into the balloon as this may cause the balloon to become overinflated. Overinflation of the balloon may result in damage to the vessel wall and/or vessel rupture and/or balloon rupture.
   - Note: If balloon pressure is lost and/or balloon rupture occurs, deflate the balloon and remove the catheter and introducer sheath as a unit.
8. Secure the catheter to the patient appropriately using standard techniques to prevent device migration.

Balloon Deflation, Withdrawal, and Removal

9. Completely deflate the balloon by opening the balloon stopcock and drawing a vacuum using the syringe. If contrast media is used to inflate the balloon, complete deflation may be confirmed using appropriate medical imaging, i.e., conventional x-ray or fluoroscopy. Close the stopcock.
   - Note: Allow adequate time for the balloon to completely deflate (i.e., confirm that inflation medium is no longer reentering the syringe before closing the stopcock and releasing the vacuum).
10. Disengage or detach the method/device used to secure the catheter to the patient.
11. Carefully withdraw the catheter until the catheter has been completely removed from the introducer sheath using standard techniques. The catheter may be rotated during withdrawal to ease removal through the introducer sheath.
    - Note: If difficulty is encountered when removing the catheter, remove the catheter and introducer sheath as a unit.
12. Remove the introducer sheath and close the access site using standard techniques.
13. After use, the device may be a potential biohazard. Handle and dispose of it in accordance with accepted medical practice and with applicable local, state, and federal laws and regulations (applicable local, national, and EU laws and regulations for CE use) (Fig. 10.4).

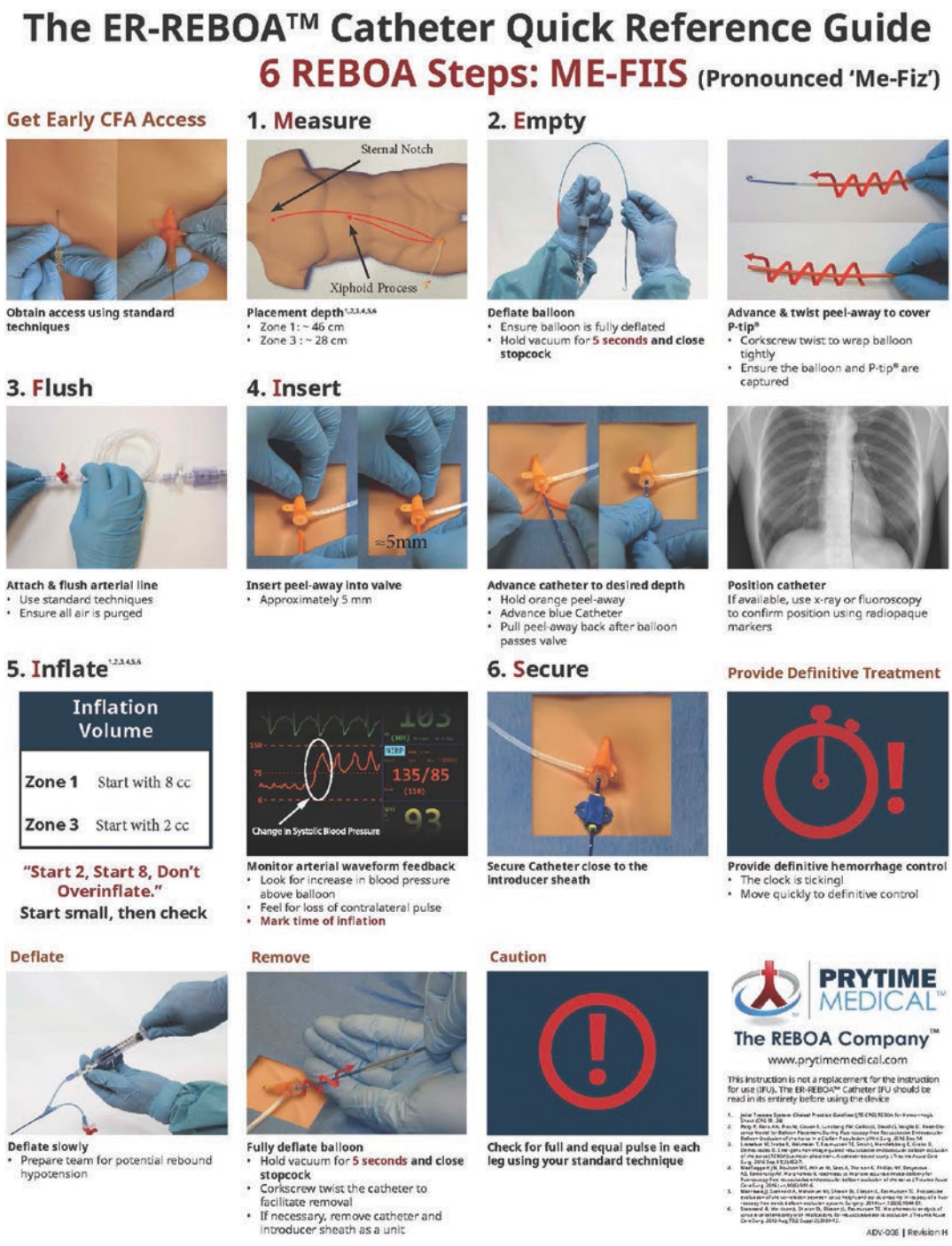

Fig. 10.4 REBOA procedure. (Courtesy of www.prytimemedical.com)

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Arterial Line Access and Monitoring

11

Aimee M. Abide and Heather H. Meissen

Introduction

Arterial cannulation is an established invasive procedure frequently performed in acute and critical care settings and is indicated for dynamic interpretation, management, and manipulation of blood pressure [1]. Intra-arterial monitoring is a superior measurement of blood pressure and mean arterial pressure compared to noninvasive methods such as blood pressure cuffs. Continuous and precise blood pressure measurements allow for acute recognition of hemodynamic variation, leading to rapid interventions and stabilization of a patient [2]. In addition to accurate blood pressure monitoring, arterial cannulation also serves as intravascular access for frequent arterial blood sampling such as arterial blood gases. Arterial cannulation prevents additional punctures, subsequently decreasing the potential for arterial injury. Historically, physicians performed arterial catheterization. As healthcare organizations move to more cost-friendly practices, many institutions are now credentialing advanced practice providers (APPs) such as nurse practitioners (NPs) and physician assistants (PAs) for this procedure. Arterial cannulation should only be performed by a licensed and credentialed provider who has exhibited competency in this procedure. This chapter will review general principles of arterial line access and outline specific techniques for placement of arterial lines [1–4].

Indications [1–4]

Placement of an invasive intra-arterial catheter is indicated in the following circumstances:

- Accurate measurement of intra-arterial blood pressure.
- Accurate measurement of mean arterial pressure.
- Frequent arterial blood sampling for laboratory analysis, such as arterial blood gas.
- Facilitate titration of vasoactive medications.
- Inability to obtain noninvasive blood pressure monitoring, as in patients with burns, severe hypotension, multiple fractures, or morbid obesity.
- Utilize arterial pulse pressure as a surrogate of stroke volume [5].
- Usefulness in determining fluid responsiveness utilizing changes in arterial pressure waveform during positive pressure ventilation [6, 7].

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Contraindications [2, 3]

There are several contraindications to placement of an invasive arterial line.

Absolute contraindications:

- Inadequate or interrupted collateral circulation
- Absent pulse
- Thromboangiitis obliterans (Buerger's disease)
- Full-thickness burns over the cannulation site
- Raynaud's syndrome

Relative contraindications:

- Systemic anticoagulation or uncontrolled coagulopathy
- Arterial atherosclerosis
- Synthetic arterial or vascular graft
- Insufficient (reduced but not absent) collateral perfusion
- Infection at the cannulation site
- Partial thickness burns at cannulation site
- Previous surgery in the area

Site-Specific Considerations of Risks and Benefits

In adults, radial, brachial, or dorsalis pedis sites are preferred over the femoral or axillary sites to reduce the risk of infection (CDC Category IB) [8]. See Table 11.1 for a list of specific advantages and disadvantages in the catheterization of the peripheral and central arterial sites [9, 10].

In addition to site selection, it is important to consider the effect of the arterial cannulation site on the measured blood pressure. As the monitoring site is moved further distally in the arterial tree, the systolic blood pressure increases and the diastolic blood pressure decreases when compared with central arterial pressure. However, the mean arterial pressure remains the same between the various peripheral and central arterial sites [6].

Table 11.1 Site-specific considerations of arterial cannulation

	Advantage/benefit	Disadvantage/risk
Radial	Most common Generally accessible Collateral dual blood supply to hand (Radial a. and ulnar a.) Low complication rate	In vascular disease, may be small or calcified Difficult to access if patient is on vasopressors Limited hand mobility
Brachial	Available when radial site is not Relative ease of identification	No redundant blood supply, risk of distal ischemia Uncomfortable Risk of median nerve injury Cannot flex arm
Femoral	Large vessel Easily accessed Can give accurate values in vasoconstrictive states	Higher risk of catheter-associated infection Risk of retroperitoneal hematoma
Axillary	Higher comfort level for patient	Higher risk of catheter-associated infection Risk of brachial plexus end artery injury
Dorsalis pedis	May be accessible when other sites are not Excellent collateral flow Ease of cannulation	Potential amplification of waveform

The advantages and disadvantages for arterial cannulation at specific anatomical sites are shown in this table [9, 10]

Preparation

Basic equipment needed for arterial cannulation and catheter placement [2, 4]:

- Sterile gown and gloves, hair cap, mask, and drape
- Skin prep solution (povidone iodine or chlorhexidine)
- Flexible catheter/angiocatheter or catheter over the guidewire
- Monitoring system with pressure-transduction tubing
- 5 cc 1% lidocaine without epinephrine
- 3 cc syringe with 25 gauge needle for subcutaneous lidocaine injection
- No. 11 blade scalpel
- 4-0 nylon/2.0 silk suture or adhesive tape
- Sterile 4 × 4 s
- Needle holder
- Clear bio-occlusive dressing/sterile dressing to cover cannula

Additional equipment needed for site specific arterial catheterization:

- For placement of radial artery catheters:
  - Dorsal wrist extensor splint
  - Small rolled up towel

Ultrasound equipment:

- Ultrasound machine
- 5–10 MHz linear array ultrasound transducer
- Sterile ultrasound gel
- Sterile ultrasound transducer cover

Preparation for arterial catheter insertion begins by gathering all needed equipment both for the procedure and for the monitoring system. Many institutions have commercially prepared arterial line kits that contain the equipment routinely used in arterial catheter insertion [4]. These kits contain different items and are customizable to meet the needs of the provider. Figure 11.1 shows an example of a commercially prepared arterial line kit that includes the catheter over guidewire. Additionally, these kits can be tailored to meet the needs for femoral artery cannulation.

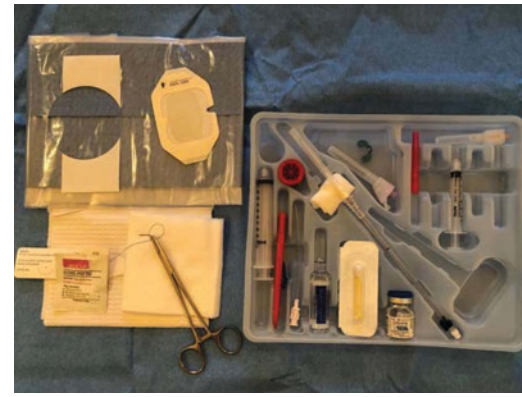

Fig. 11.1 Commercially prepared arterial line kit with catheter over the guidewire. Contents include sterile drape, sterile dressing, suture and needle driver, 10 cc and 5 cc syringes, scalpel, sterile sodium chloride and lidocaine, various size needles, and catheter over the-guidewire

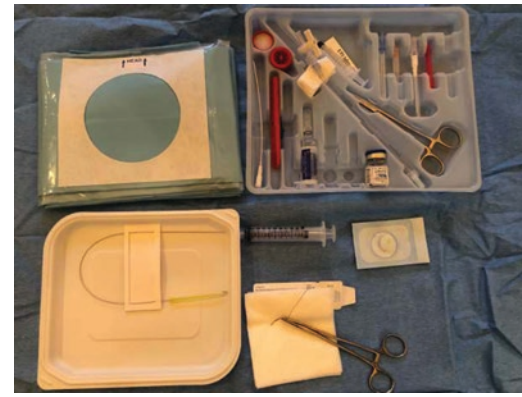

Fig. 11.2 Commercially prepared arterial line kit with longer catheter and separate guidewire. Contents include sterile drape, sterile dressing, suture and needle driver, scalpel, sterile sodium chloride and lidocaine, various size needles, angiocath and long flexible catheter with separate guidewire

Figure 11.2 is an example of a commercially prepared femoral arterial kit. Figure 11.3 demonstrates the various available lengths. Prior to starting a procedure, it is the responsibility of the provider to receive proper training. The provider must also be familiar with available kits in their institution to reduce the risk of error.

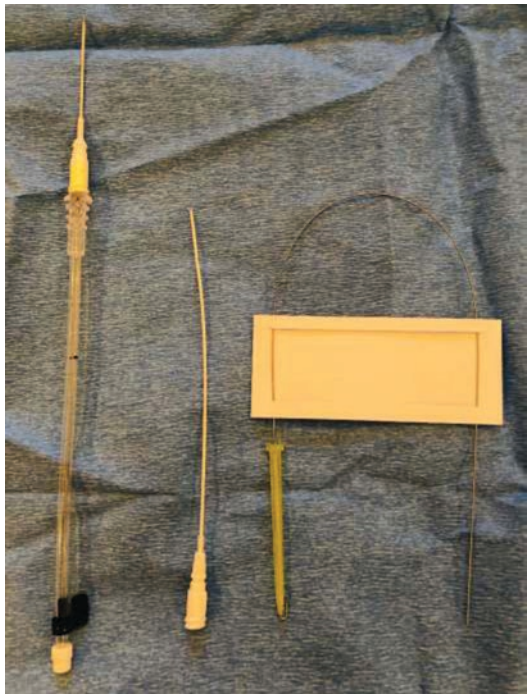

Fig. 11.3 Different lengths of arterial catheters. (**a**) Radial artery catheter, (**b**) femoral artery catheter, and (**c**) guidewire for femoral catheter

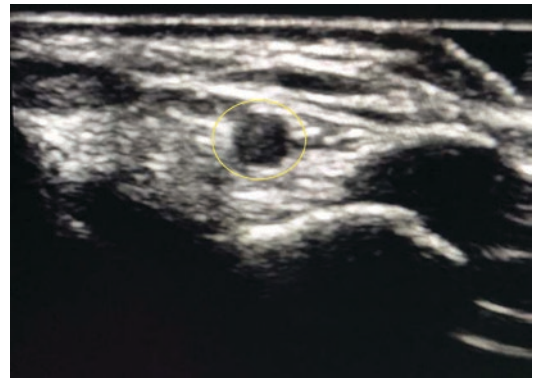

Fig. 11.4 Short-axis image of the radial artery (yellow circle)

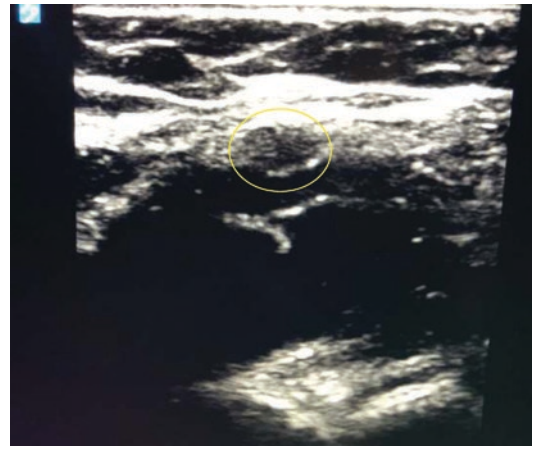

Fig. 11.5 Short-axis image of the brachial artery (yellow circle)

Ultrasound is a valuable tool for placement of arterial lines, especially as a rescue method if direct palpation is unsuccessful. Ultrasound for arterial cannulation has become a common adjunct to support arterial line placement because of its ability to easily visualize the target vessel [11]. In a study by Bhattacharjee, Maitra, and Baidya [12], use of ultrasound during arterial cannulation demonstrated improved first attempt rates compared to traditional digital palpation techniques [12]. Ultrasound can be helpful to decrease the number of puncture attempts, to decrease the amount of time spent obtaining access, and to decrease complications such as hematomas [1]. The use of ultrasound as an aid for radial artery cannulation is considered best practice by some experts [1]. Figures 11.4 and 11.5, respectively, are short-axis images of the radial and brachial arteries using ultrasound. It is the responsibility of the provider to be trained and competent with ultrasound prior to use.

When preparing to place intra-arterial catheters, it is helpful to have at least one other member of the healthcare team available to assist. This additional team member can help with the non-sterile aspects of the procedure such as connection of equipment and patient monitoring. Additional team members can include the bedside nurse or provider.

Positioning of the patient is a vital step in the preparation of arterial line catheterization. Proper

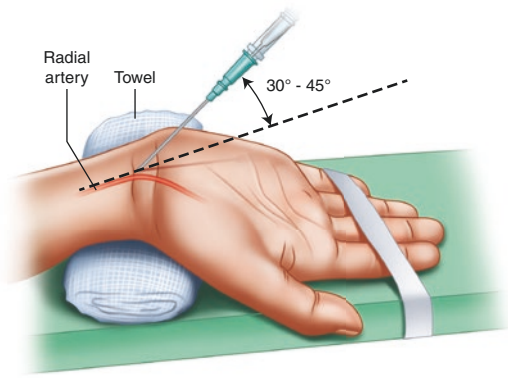

Fig. 11.6 Correct positioning for radial artery cannulation. In order to create maximum procedural space and to facilitate palpation of the radial artery, place the wrist in dorsiflexion and support it with a small towel. Palpate the radial artery with the nondominant hand and position the needle or catheter over the needle at a 30°–45° angle to the skin

positioning can reduce need to reposition once the site is sterile. Proper positioning will allow for a smoother procedure overall. The most preferred peripheral arterial site is the radial artery. Proper positioning for the radial artery will include wrist extension and immobilization over a padded arm board. A roll of gauze placed under the wrist can also achieve dorsiflexion of wrist and arm abduction [1, 4]. Figure 11.6 demonstrates the correct positioning for radial artery cannulation. The next most common peripheral site are the brachial and dorsalis pedis sites. Proper positioning of the brachial site includes full extension of the arm. The provider will palpate the pulse at the antecubital fossa [1, 4]. Proper positioning of the dorsalis pedis site requires the lower extremity be straightened and plantar flexion of the foot. If plantar flexion is more than 45°, there is increased risk of occluding the artery [1, 4]. The preferred central arterial sites include the femoral and axillary sites. The femoral artery is the most commonly accessed central arterial site [1, 4]. Proper positioning of the femoral site will require hip abduction. For maintenance of patency after the placement of the line, the extremity will need to remain straightened. The proper position for axillary catheterization is to place the arm in abduction, slightly externally rotated, raised, and flexed at the elbow. Occasionally the arm is taped into position using tape to secure the arm. The peripheral arteries are located more easily and have a lower infection risk as compared with central arterial sites [1, 4, 13].

Assessing adequate collateral flow is an important step in patients undergoing peripheral arterial catheterization. Specifically for radial artery intersection, a physical examination that includes the Allen's test or modified Allen's test (Fig. 11.7) is important to identify patients at increased risk for an ischemic complication [1].

Knowledge of the arterial anatomy is another key factor in the preparation for arterial puncture and cannulation. In order to avoid complications, it is vital to recognize that nerves and veins are in close proximity. Figures 11.8, 11.9, 11.10, 11.11, and 11.12 demonstrate anatomy for the radial, brachial, axillary, femoral, and dorsalis pedis artery.

Procedure

- Local anesthetic injection is commonly used at the site of insertion. Injection of local anesthetic does not adversely impact the success of the procedure and may reduce vasospasm [8, 13].
- Arterial catheters are placed under sterile conditions.
  - Access sites are prepared with standard techniques [13].
  - An antiseptic solution of either povidone iodine or chlorhexidine is applied to the access site and allowed to dry.
  - The procedure is performed with sterile gloves and a fenestrated drape. The fenestrated drape should be positioned after the antiseptic solution is dry on the skin [14].

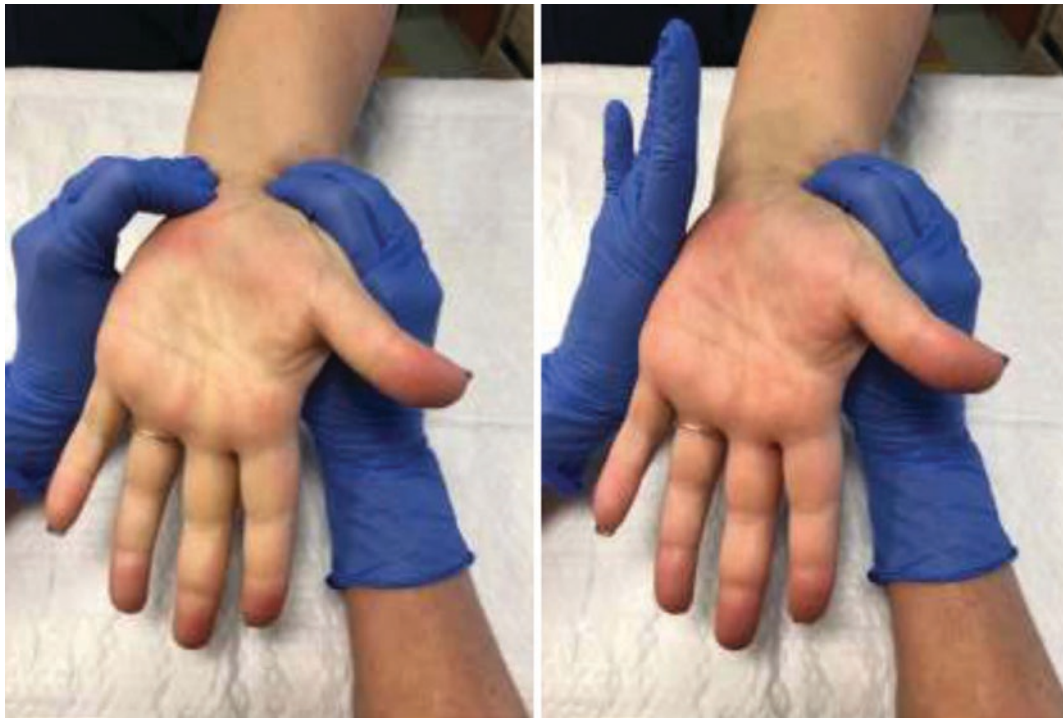

Fig. 11.7 Modified Allen's test. (**a**) Occlude both distal radial and ulnar arteries to observe blanching of the hand. (**b**) The radial artery remains occluded to assess if the ulnar artery can adequately supply blood to the hand. Adequate ulnar supply will return blood to the hand [1]

– For central arterial access sites (femoral, axillary), full barrier precautions including masks, caps, and eye protection can be used to reduce the potential for catheter site infection and minimize risk for disease transmission associated with blood splatter [8, 14].

Procedural approach should be determined prior to beginning the procedure. Two common techniques include catheter-over-needle approach (Fig. 11.13) and Seldinger technique (Fig. 11.14). Seldinger approach can be used by either an integrated catheter-over-guidewire one piece unit or separate catheter and guidewire.

Catheter Over Needle

- Clean, prep, and identify the radial artery.
- Position the catheter over needle at a 30°–45° angle to the skin and directly over the arterial pulse.
- Insert the catheter over needle into the artery, and bright red blood return indicates puncture of the artery.
- Advance the catheter over needle an extra 2–3 mm to ensure that the catheter is well seated within the lumen of the artery.
- Secure the hub of the needle.
- Advance the catheter over needle until the hub is at the skin.

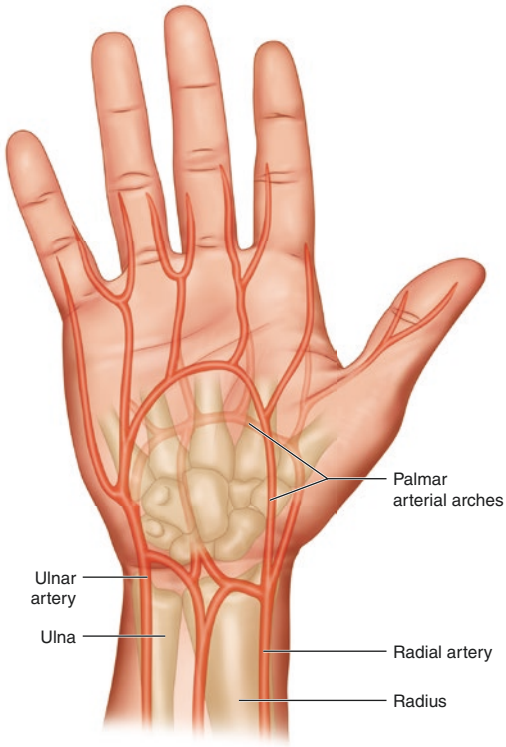

Fig. 11.8 Anatomic location of the radial artery. Collateral circulation is supplied by the palmer arterial arches. The radial artery can be accessed on the ventrolateral aspect of the wrist. The radial artery is palpable at the wrist, proximal to the radial styloid or radial head, and slightly lateral. The cannulation site should be at the very distal portion of the arm. The most frequent location for radial artery cannulation is at the proximal flexor crease of the wrist, 1 cm proximal to the styloid process

- Remove the needle and confirm pulsatile blood flow from the catheter.
- Pulsatile arterial flow confirms proper placement of the catheter within the artery.
- Apply a stopcock or intravenous (IV) tubing to the hub of the catheter.
- Secure the catheter to the skin by either suture or commercially available devices.
- Apply a sterile dressing and the use of an antiseptic-impregnated patch which may help decrease incidence of catheter-related bloodstream infections [1].

Seldinger Technique

Seldinger technique is utilized when a sharp hollow needle is used to puncture the desired artery. The syringe is detached and a guidewire is advance through the lumen of the needle. The needle is removed, and a catheter is passed over the guidewire and into the artery (Fig. 11.14). Modified Seldinger technique is the technique of using a smaller catheter over the needle to be advanced into the artery and removing the needle. Once the smaller catheter is in place, the guidewire is inserted into the catheter into the artery. The small catheter is removed over the guidewire, and main arterial catheter is advanced over the guidewire, into the artery, and the guidewire is removed.

Additionally, Seldinger technique can be utilized with the prepackaged commercially available catheter over wire (Fig. 11.15). The Seldinger technique is particularly useful for the access of central vessels that run deeper within the extremity [3]. When the package is opened and catheter over wire removed, be sure to remove the protective cover over the needle. It is a useful practice to test the equipment and slide the guidewire back and forth to ensure it moves smoothly.

Radial Artery Cannulation

- Clean and prep the skin.
- Identify the arterial pulse with the nondominant hand and position the tip of the needle at a 30°–45° angle at the skin and directly over the arterial pulse.

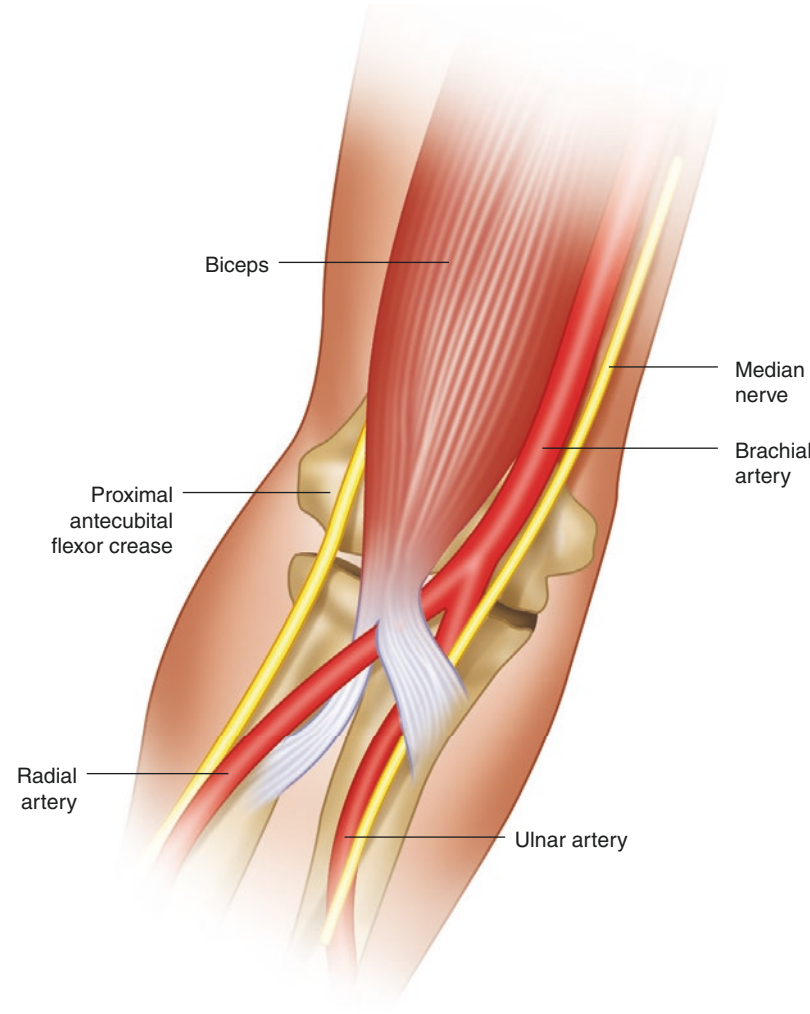

Fig. 11.9 Anatomic location of the brachial artery. The brachial artery is located on the medial aspect of the antecubital fossa. Palpate the brachial artery pulse just medial to the biceps muscle. The brachial artery divides at the level of the radial neck to become the radial and ulnar arteries

- Insert the catheter over wire through the skin and into the artery with a slow continuous movement. A flash of bright red blood into the hub and up the sheath confirms entry into the radial artery.
- Lower the angle of the unit closer to the wrist and slide the guidewire into the artery.
- To ensure you are within the arterial walls, when the guidewire is retracted, there will be a continuous column of blood extending backwards and into the sheath.
- Extend the guidewire by using the lever, pushing it toward the hub of the catheter. There should not be resistance as the guidewire is advanced, and meeting resistance should indicate improper position. If there is resistance, do not force the guidewire into the vessel but remove the entire unit and apply pressure to prevent a hematoma. Obtain a new kit and repeat the procedure.
- Once the guidewire is fully advanced into the arterial lumen, secure the hub of the needle and advance the catheter over the wire and into the artery.
- A gentle rotation of the catheter helps slide it into place. Secure the catheter at the skin and

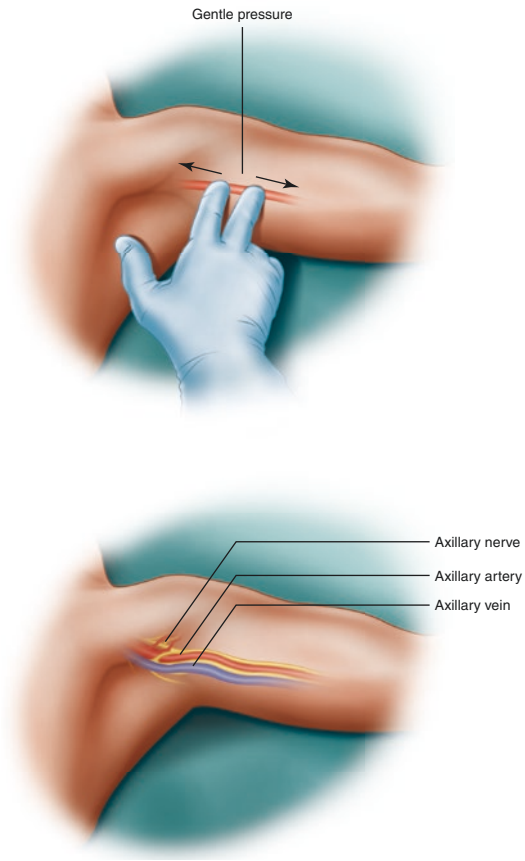

Fig. 11.10 Anatomic location of axillary artery. The axillary artery is a continuation of the subclavian artery after it passes the first rib. The site of the axillary artery can be deep to the surface on the skin, but an advantage of this artery is the relative ease of palpating the pulse. The position of the arm should be abducted and externally rotated

remove the guidewire. Free-flowing pulsatile blood confirms proper placement.
- Apply a stopcock or IV tubing to the catheter.
- Secure the catheter to the skin by either suture or commercially available devices.
- Apply a sterile dressing and the use of an antiseptic-impregnated patch which may help decrease incidence of catheter-related bloodstream infections [1].

Brachial Artery Cannulation

If the radial artery is inaccessible, the brachial artery can be used. Either technique for Seldinger can be used, with either the catheter over needle or the catheter over guidewire. Potential disadvantage for the brachial arterial site is the patient discomfort from maintaining the arm in an extended position as flexing the arm can occlude the catheter. Distal ischemia can also occur with brachial artery cannulation.

- Extend the arm completely and palpate the pulse at the antecubital fossa.
- Prep, drape, and anesthetize the area.
- Maintain the fingers of the nondominant hand to locate the pulse.
- Insert the needle at a 30°–45° angle to the skin.
- Follow the remainder of the steps as previously described for radial artery cannulation.

Axillary Artery Cannulation

If attempt for radial cannulation is unsuccessful, the axillary artery can be used. A longer catheter and separate guidewire may be needed to access the axillary artery.

- Prep, drape, and anesthetize the area.
- Maintain the fingers of the nondominant hand on the axillary pulse, which can be located near the concavity of the axilla.
- The insertion angle is smaller than used for radial arterial cannulation.
- Insert the needle at a 15°–30° angle to the skin and aim the needle at the place where the pulse is most strongly palpated.
- Once pulsatile blood flow is confirmed, follow the remainder of the steps as previously described for radial artery cannulation.

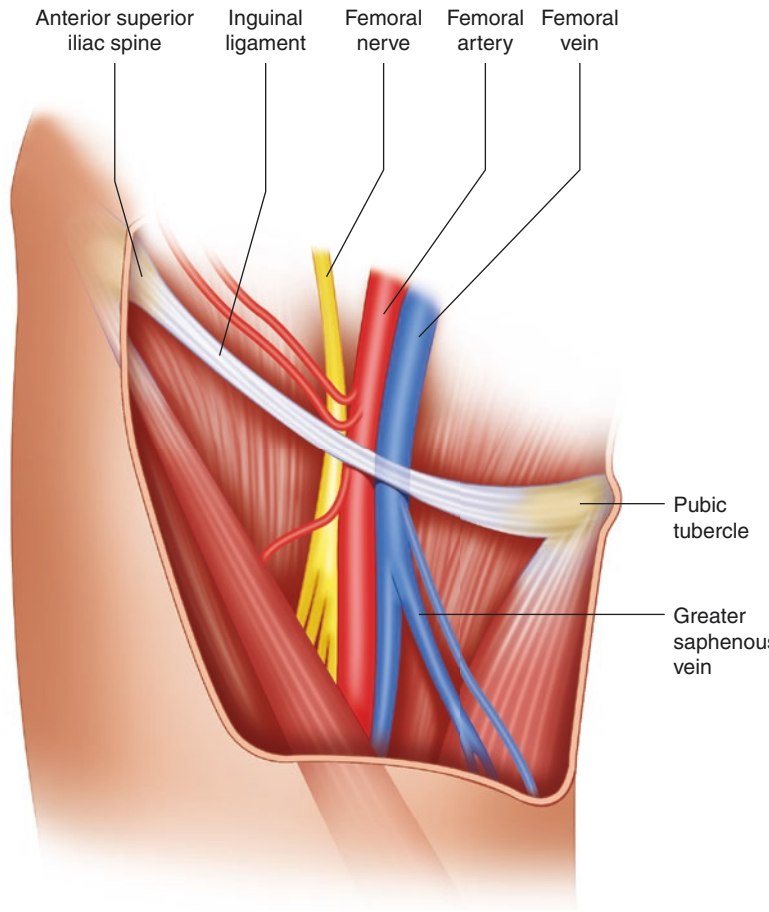

Fig. 11.11 Anatomic location of the femoral artery. The femoral artery is largest among the arteries used for cannulation. It also lies deeper than the peripheral arteries, so a longer cannula may be necessary. The bony anatomic landmarks that can be used to identify the femoral artery are the anterior superior iliac spine and the tubercle of the pubic symphysis. The femoral artery can be palpated midway between these two structures and under the inguinal ligament. To maximize access to the femoral triangle, slightly abduct the hip and extend the leg. Pay attention to the close proximity of the femoral nerve and vein

Femoral Artery Cannulation

The femoral artery may be cannulated if the radial artery is unable to be used or attempts at catheterization are unsuccessful. A longer catheter and separate guidewire may be needed as the femoral artery location is frequently deeper, especially in obese patients.

- Prep, drape, and anesthetize the skin and subcutaneous tissue.
- Use the fingers on the nondominant hand to find the pulse and use that insertion site.
- Insert the needle at a 45° angle to the skin and keep the bevel of the needle pointing superiorly and into the femoral artery.
- The rest of the procedure is as previously described in radial artery cannulation.

Dorsalis Pedis Cannulation

Use of the dorsalis pedis artery may be a good second choice if the radial artery is unavailable or unable to be cannulated. The risk of foot ischemia is minimal due to the collateral blood supply.

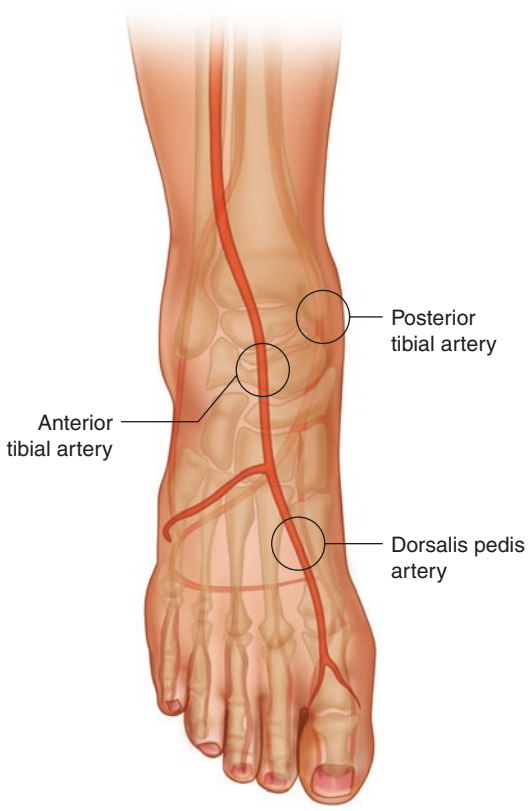

Fig. 11.12 Anatomic location of the dorsalis pedis artery. The dorsalis pedis artery is a continuation of the anterior tibial artery. The pulse can be palpated between the first and second metatarsal on the dorsal surface of the foot

Additionally, the distal location of the dorsalis pedis artery makes it a convenient place for a patient to have an invasive line. The technique to cannulate the dorsalis pedis artery is similar to the method described in catheterization of the radial artery.

- Prep, drape, and plantar flex the foot.
- The angle of the needle should be less than the angle used for the radial due to the shallow location of the dorsalis pedis artery.
- Insert the needle with a 20°–30° angle.
- The rest of the procedure is as previously described in radial artery cannulation.

Complications

Intra-arterial puncture and cannulation are generally safe procedures with an incidence of clinically significant complications of less than 5% [1, 15]. The most common complications of arterial catheterization is vascular insufficiency (3–5%), bleeding (1.5–22.5%), and infection (<1%) [6]. Proper site selection, sterile technique, and ultrasound guidance during cannulation can minimize complications [13].

Complications of arterial catheterization [9]:

- Pain/swelling
- Bleeding/hematoma (1.5–22.5%)
- Distal Limb ischemia
- Pseudoaneurysm/arteriovenous fistula
- Catheter-associated thrombosis or infection (<1%)
- Peripheral nerve injury
- Thrombosis/embolization
- Diagnostic blood loss

Complications of arterial catheterization at specific arterial sites [9]:

- Radial artery
  - Cerebral embolization
  - Peripheral neuropathy
- Brachial artery
  - Cerebral embolization
  - Median nerve damage
- Axillary artery
  - Cerebral embolization
  - Brachial plexopathy

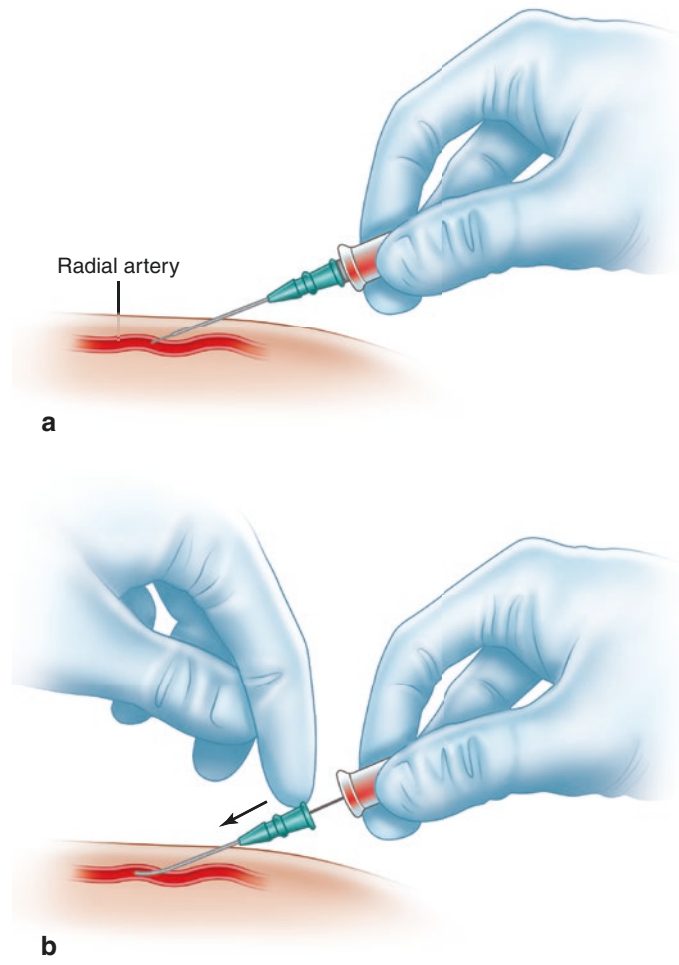

Fig. 11.13 Radial artery cannulation: Catheter-over-needle technique. (**a**) Position for entry is at a 30°–45° angle to the skin and inserted into the artery. (**b**) Next advance the catheter over the needle and into the artery

- Femoral artery
  - Retroperitoneal hematoma (Table 11.2)

"Pro-tips"

- When placing a radial arterial line, don't forget to lower the catheter toward the wrist to allow the guidewire to advance smoothly into the artery.
- Remember continuous blood flow up the column of the sheath, prior to guidewire advancement, ensures proper placement.
- The radial artery is superficial; most providers will go too deep and past the artery if not careful.
- After three unsuccessful attempts, change site or change proceduralist.
- Remember the ultrasound is your friend, especially if the patient is hypotensive.
- ALWAYS set up your kit the same way; keeping your routine reduces mistakes on your part. See Appendix 11.1 for an example of arterial catheterization competency checklist.
- The brachial artery is an end artery; avoid this site if other sites are available.

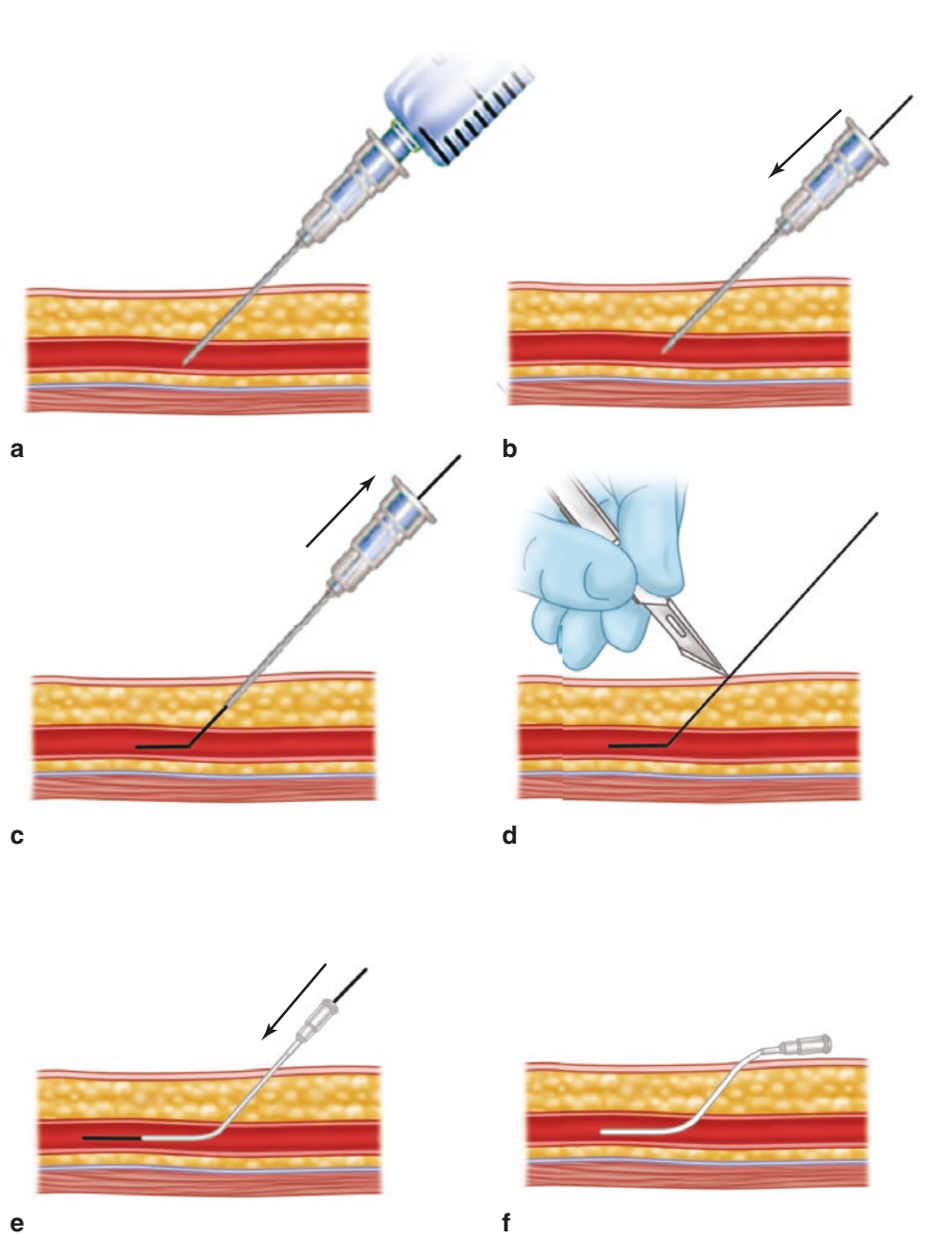

Fig. 11.14 Seldinger technique for arterial cannulation. Catheterization of the femoral artery can be facilitated by using Seldinger technique. (**a**) The needle is inserted into the artery. (**b**) Remove the syringe from the needle for blood return. Advance the guidewire through the needle and into the artery. (**c**) Remove the needle over the guidewire while leaving the guidewire in place. (**d**) If needed to facilitate ease of catheter insertion, the skin can be punctured with a scalpel blade. (**e**) Advance the catheter over the guidewire and into artery. (**f**) Remove the guidewire

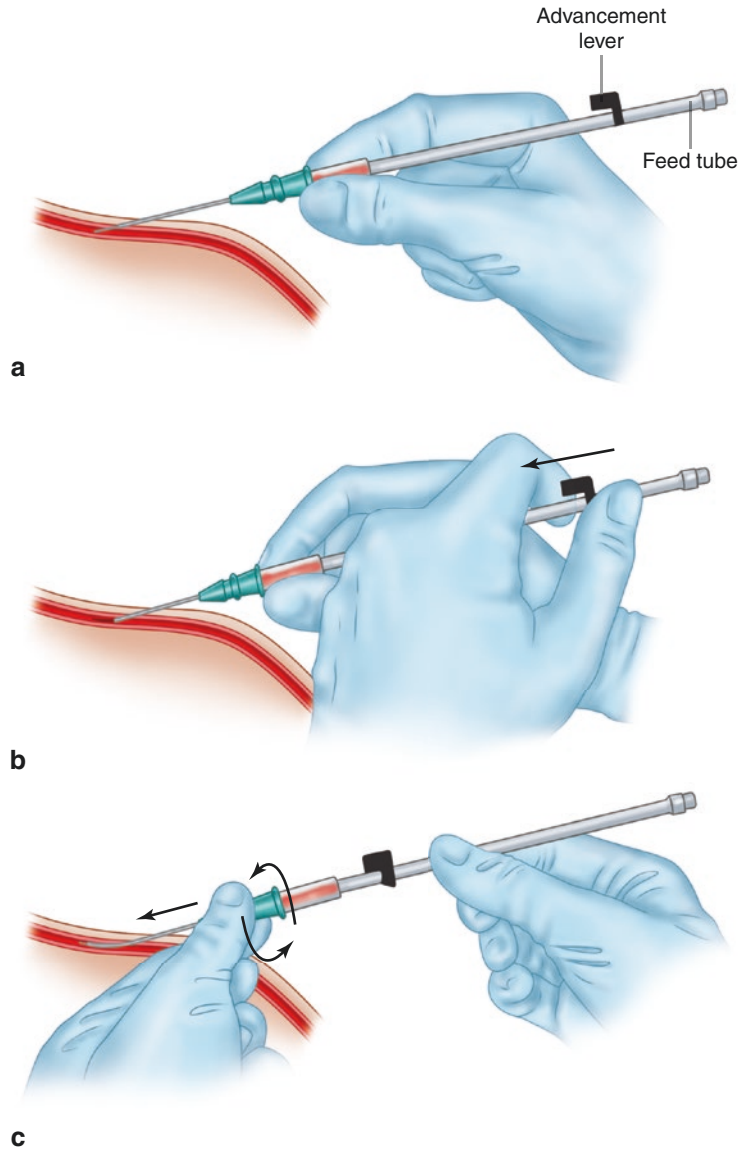

Fig. 11.15 Radial artery cannulation: Seldinger style with catheter-over-wire technique. Commercially available kits include a prepacked single use catheter over a guidewire. (**a**) Position for entry is at a 30°–45° angle to the skin and inserted into the artery. (**b**) Next advance the guidewire through the needle and into the artery. (**c**) Lastly advance the catheter over the guidewire into the artery with a gentle rotation

- There is a smaller gauge catheter over the wire, a 22 g, for those patients who are vasoconstricted or have vascular disease.
- The guidewire can occasionally be useful for salvaging an arterial line when there is difficulty with advancing the catheter.

Table 11.2 Suggested prevention and treatment options for complications of arterial cannulation

Complication	Prevention	Treatment
Thrombosis/embolization	Use smaller catheter into larger artery Decreased duration Decrease manual flushes Diligent catheter care Avoid axillary access	Remove cannula May need anticoagulation or vascular intervention
Vascular spasm	Smaller catheter Larger artery Avoid multiple attempts	Remove cannula Remove and replace as needed
Bleeding/diagnostic blood loss	Minimize connections Diligent catheter care	Control bleeding
Infection	Diligent catheter careObservation	Remove cannula Remove and replace as needed Elevate area Empiric antibiotics
Damage to nearby structures/ pseudoaneurysm/arteriovenous fistula	Careful insertion technique	Vascular or surgical intervention

Based on data from Ref. [16]

CPT Coding

CPT Coding	Category	Code	Level
Arterial catheterization without ultrasound guidance	Cardiovascular	36620	Arterial catheterization/cannulation; monitoring (spec prov); percutaneous
Arterial catheterization with ultrasound guidance	Radiology	76937	Ultrasound guidance; vascular access;

Summary

Arterial line placement is a common procedure performed in the intensive care unit. Arterial catheterization is an appropriate procedure for patients who need continuous blood pressure monitoring or frequent blood sampling. Although generally considered to be a safe procedure with few serious complications, considerations of appropriate site selection, contraindication, and potential complication are important to consider prior the insertion of an arterial line [4]. Best practice recommendations for arterial line placement include using ultrasound guidance, sterile technique, site selection, and placement by trained staff [8].

Appendix 11.1

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Arterial Catheterization Competency Checklist

For Critical Care Medicine Advanced Practice Providers

Provider Name:

Date:

Checked by:

PT MRN:

Arterial Catheterization Checklist

	Yes	Yes (w reminder)	No/ comments
Patient/family consent			
Time out			
Identify appropriate site; use ultrasound to assess size and patency of vessel			
Patient appropriately positioned			
Skin prep performed with alcoholic chlorhexidine 2% (must be dry before needle insertion)			
Clean hands			
Wear mask, sterile gloves, and eye protection if in contact with or crossing the sterile field at any time during the procedure. If femoral/axillary site, full sterile gown required			
Drape the area with sterile towels or sterile drape			
Ultrasound is recommended for all sites with utilization of sterile placement of probe cover			
Anesthetize skin with lidocaine			
Slowly advance needle tip with bevel up under ultrasound visualization until the needle tip is in the vessel and a flash of pulsatile blood is seen			
For radial artery kit: Advance the guidewire and then advance the angiocatheter into the artery			
Remove needle and wire apparatus			
For all other sites: Remove syringe and advance the guidewire through the needle			
	Yes	Yes (w reminder)	No/ comments
Remove needle while holding control of wire			
Place angiocatheter over the wire while controlling wire at all times and advance catheter into artery			
While holding pressure, remove wire			
Attach pressure transducer tubing			
Secure line with suture if needed			
Use transparent sterile dressing			
Confirm arterial placement by waveform tracing			

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Arterial Catheterization Checklist

- Patient/family consent.
- Time out.
- Identify appropriate site; use ultrasound to assess size and patency of vessel.
- Patient appropriately position.

- Skin prep performed with alcoholic chlorhexidine 2%. Scrub back and forth with chlorhexidine with friction for 30 seconds; allow to air dry completely before puncturing site. Do not wipe, fan, or blot. Groin prep with scrub for 2 minutes and allow to dry for 2 minutes to prevent infection.
- Clean hands.
- Wear mask, sterile gloves, and eye protection if in contact with or crossing the sterile filed at any time during the procedure. If femoral/axillary site, full sterile gown required.
- Drape the area with sterile towels or sterile drape.
- Ultrasound is recommended for all sites with utilization of sterile placement of probe cover.
- Anesthetize skin with lidocaine.
- Slowly advance needle tip with bevel up under ultrasound visualization until the needle tip is in the vessel and a flash of pulsatile blood is seen.
- For the radial artery kit: Advance the guidewire and then advance the angiocatheter into the artery.
- Removed needle and wire apparatus.
- For all other sites: Remove syringe and advance the guidewire through the needle.
- Removed needle while holding control of wire.
- Place angiocatheter over the wire while controlling wire at all times and advance catheter into artery.
- While holding pressure, remove wire.
- Attach pressure transducer tubing.
- Secure line with suture if needed.
- Use transparent sterile dressing.
- Confirm arterial placement by wave form tracing.

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Additional Resources

The following is a link to the CDC guidelines for the Prevention of Intravascular Catheter-Related Infections (2011). https://www.cdc.gov/infectioncontrol/guidelines/bsi/index.html.

12 Central Venous Catheterization With and Without Ultrasound Guidance

Ryan O'Gowan and Stephen Paul Callahan

Overview

Central venous catheter (CVC) placement is the most commonly performed procedure in the ICU with over five million CVC lines being placed each year in the USA alone. CVC lines first began utilization in early 1966 [1]. Their use and implementation are ubiquitous in the ICU, and routine placement has become a part of many care bundles, including early goal-directed therapy (EGDT) for sepsis. Moreover, CVC lines have become an integral part in the management of the critically ill, with minimally invasive cardiac output monitoring being a significant factor for placement [2]. They are required for a number of vasopressors, inotropic agents, antibiotics, and medications which may pose a risk of extravasation. The first reported use of ultrasound (US) technology to aid in the cannulation was in 1984. Although initially there was a lack of adoption of this vital technology, a recent survey among resident physicians has found a utilization rate of 90% in the internal jugular site with US guidance becoming the sine qua non for CVC placement [3, 4]. Prior to the widespread adoption of US technology, clinicians had a significant failure rate using traditional anatomic landmarks with some authors citing a failure rate of 19.4% [5]. Lastly, even in highly experienced operators, reliance on traditional landmark techniques may result in a sixfold increase in complication rate when more than three attempts are made at vascular access in a given site (Subclavian, Internal Jugular) [6].

Review of Ultrasound Technology

Traditional ultrasound techniques include the use of a linear array probe and B-mode (brightness mode) ultrasound. This is in contrast to other types of probes (phased array) and modes (M or motion mode) used for indications other than CVC placement. The ultrasound machine utilizes a piezoelectric effect to utilize energy along the ultrasound crystal array to create an image of the anatomic structure of interest. Typically frequencies for procedural use operate in the range of 2–15 MHz. Variables that may be controlled include the depth and gain to create a clearer image for CVC placement. Additionally, the views utilized may consist of short-axis views, long-axis views, or a combination (biplanar) approach [7]. There has been some debate over the superiority of the short-axis approach

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as opposed to the long-axis approach for vessel cannulation. However, a prospective randomized study showed that success rates in the short-axis group, while higher, were not statistically significant [8]. Although there is less of a difference in short-axis vs. long-axis techniques, success rates for US vs. traditional landmark techniques are drastically different with one author citing success rates of 93.9% with US in comparison with 78.5% using landmarks alone. Further techniques to provide for a more optimal US image of the needle include placing the bevel side down so as to be in the plane of the US transducer and the use of commercially available echogenic needle tips. Lastly, commercial needle guides may be available for utilization to facilitate optimal needle placement with an incidence angle of 30°–45°.

Indications

Owing to its ubiquitous use in the critical care environment, there are a multitude of indications for the placement of a CVC catheter [9]. Hemodynamic monitoring is one of the most frequent reasons. Interestingly, some complications in SC CVC placement may actually be lower than PICC catheters. One study found that rates of thrombophlebitis were lower in SC CVC catheters when the reason for placement was TPN administration [10]. Common indications for CVC placement are outlined as follows in Table 12.1.

Table 12.1 Indications

Intravenous fluid administration
Hemodynamic monitoring
Total parenteral nutrition
Drug or blood product administration
Hypertonic electrolyte administration
Insertion of temporary pacing wires
Swan-Ganz catheterization
Hemodialysis access
Aspiration of air emboli

Table 12.2 Contraindications

Coagulopathy or TPA administration
Obstructing clot in central vein
Pre-existing indwelling port or chemotherapy catheter
Pacemaker or AICD

Contraindications

Common contraindications for CVC placement are outlined as follows in Table 12.2:

Anatomic Locations for Catheterization and Procedure Without US Guidance

Typical anatomic locations for CVC placement include the internal jugular vein, subclavian vein, and femoral vein. Although other sites may be utilized for the placement of peripherally inserted central catheters (PICCs), their discussion is outside of the purview of this chapter and is discussed elsewhere.

Internal Jugular Site

The internal jugular vein may be found beneath the digastric belly of the sternocleidomastoid muscle. The classic landmarks which delineate the borders of the carotid triangle include the sternocleidomastoid, trapezius, and the clavicle inferiorly. Traditionally, in a non-ultrasound approach of the right internal jugular vein, the clinician may palpate the carotid pulse medially with their non-dominant hand and insert a smaller finder needle laterally and aim at a 45° needle, inserting it in the direction of the ipsilateral nipple. It is important to initially start higher on the neck for a number of reasons. First, the internal jugular vein courses from a lateral position to the carotid to more of an anterior relationship to the vein as the internal jugular approaches the base of the neck. This relationship predisposes to

possible inadvertent cannulation of the carotid artery or hematoma if posterior wall puncture (PWP) occurs. The avoidance of PWP is of tantamount importance in the placement of large bore hemodialysis CVC catheters in this site, owing to the larger dilators that are employed [11–13]. Secondly, the risk of pneumothorax increases as the insertion site moves further toward the base of the neck as the longer cannulation needle may actually penetrate the apex of the lung, which may be extended to the space above the clavicle. Relative advantages of the internal jugular vein for CVC placement include ease of access and readily visible landmarks. Relative disadvantages for CVC placement in this location include pooling of oropharyngeal secretions in intubated patients, difficulty in placing an occlusive dressing, and potential for airway compromise in the event of carotid hematoma. Failure and complication rates for traditional placement techniques in experienced versus inexperienced operators have been listed as 11.7% and 17.6%, respectively [14]. In an observational study conducted in the ED setting, US in the IJ site was still safer in inexperienced operators as opposed to the SC site with a failure rate of 10%. In that same study, complication rates of hematomas and arterial punctures were listed as 7% and 2%, respectively [15–17]. Moreover, the use of ultrasound has been associated with a higher success rate (93.9% versus 78.5%) and a reduced time for placement when compared with the traditional landmark technique [18–20].

Subclavian Site

The subclavian vein may be found beneath the clavicle at the transition point between the proximal and middle third at the clavicle at the midclavicular line. Of note, the clinician may palpate this site and feel a firmness which signifies the ligament of Halsted. Moving laterally and inferiorly to the clavicle approximately one to two centimeters will signify the optimal point for cannulation of the subclavian vein. After appropriate cleansing, anesthetic placement, and draping, the clinician may enter the skin with the needle at a 30° angle. With the non-needle hand, once the needle is in the skin, the clinician then provides gentle downward pressure over the needle with their thumb and slowly advances toward the sternal notch and the contra lateral shoulder. Gentle aspiration is performed until a venous flash occurs. In the event that the clinician directs the needle more caudally, they may encounter a bright red arterial flash. Additionally, great care should be taken as the risk of pneumothorax is significantly higher in this anatomic site. Loss of negative pressure on the syringe may signify entry into the pleural space and subsequent pneumothorax. For patients who are intubated, clinical signs of tension pneumothorax include an increase in peak inspiratory pressures, loss of tidal volumes, or an increase in respiratory rate. Physical examination may reveal jugular venous distention or loss of breath sounds. As with the internal jugular site, failure and complication rates for traditional placement techniques in experienced versus inexperienced operators with the subclavian site have been listed as 7.5% and 15%, respectively [21]. A more detailed study of the subclavian site showed a pneumothorax rate of 2.5% and an overall complication rate of 5.5% [22].

Complications listed included tip misplacement, arterial puncture, inability to locate the vessel, and hemothorax. Interestingly, US guidance using either SA or LA approaches in the SC site has failed to show any meaningful reduction in complication rates [23, 24].

Femoral Site

The femoral vein may be located medial to the femoral artery and below the inguinal ligament. Traditionally the clinician thoroughly cleanses the groin, drapes the patient, and anesthetizes soft

tissue. Palpating the femoral pulse, the clinician inserts the needle and syringe medially, in contradistinction to the internal jugular vein which is lateral to the pulse. Of note, it is important to cannulate the vessel below the inguinal crease, as placement above the crease may cause the needle to be inserted inadvertently into the peritoneum. Moreover, placement in an extreme medial position may cause for entry into the extra lymphatic or lymphatic space.

Instances in which the femoral site is advantageous include patients who may be coagulopathic. Recall that subclavian sites may be dangerous in this case as inadvertent puncture of the subclavian artery may lead to massive hemothorax, owing to the non-compressibility of the subclavian artery. In addition, femoral catheters do not require a confirmatory x-ray to verify placement and may be used immediately. Although there have been few studies that specifically review the femoral vein as a primary cannulation site of choice, one study exploring US-guided cannulation in this site did show a significantly reduced number of venipuncture attempts (2.3 versus 5.0; $P = 0.0057$) and rate of complications (0% versus 20%; $P = 0.025$) [7]. The femoral site was traditionally a site of last resort, owing to the high likelihood of contamination, vis-à-vis the groin in earlier studies. Recent systemic literature review, however, revealed no difference in the rate of catheter-related bloodstream infection between internal jugular, subclavian, and femoral sites [25, 26].

Implementation of US Guidance for CVC Placement

Ultrasound has found an expansion in utilization owing to its relatively inexpensive cost, lack of ionizing radiation, and excellent safety profile. Moreover, in its procedural implementation, there is no need for contrast. Due to this widespread adoption, many medical schools have begun implementing formal didactics and training throughout the 4-year allopathic educational model [27]. Web-based models have found widespread success in the adoption of US CVC guidance techniques for physicians in training and have improved the base of knowledge for procedural competence [28, 29]. Techniques that may be employed include either static or dynamic techniques. Static techniques are employed by operators that may not be facile in the use of probe or when a sterile probe cover is not available. By definition, static techniques rely on the operator using the probe to gain orientation to the structure of interest, marking the skin over the vein, and placing the probe aside. Static techniques are less optimal as the operator may still hit the artery or penetrate the posterior wall of the vein. In contrast, dynamic techniques are superior with regard to avoiding complications [30]. However, they may be more challenging for junior operators to master. In the dynamic technique, the operator maintains the probe in the field at all times so that the needle may be visualized in the area of interest throughout the duration of vessel cannulation. This provides for a safer procedure, as inadvertent puncture of the nearby artery or the posterior wall is avoided. The author utilizes a technique where in right-sided IJ placement via US, the thenar aspect of the left hand is lightly steadied on the patient's jaw. This enables the operator to maintain the probe in an optimal perpendicular plane. A good view will reveal the IJV to be circular, whereas an off-axis view will provide an oblong appearing IJV. At this point, the operator should test for compressibility of the IJ (see Fig. 12.1).

Utilizing the dynamic technique with a short-axis view, the operator then slowly advances the needle at a 30°–45° angle with the bevel up, looking for a "V" indentation on the anterior aspect of the IJV. The needle is advanced until a dark red venous flash is obtained. It should be cautioned to not advance if the flash is lost, as this may signify penetration of the posterior wall of the vessel. See Fig. 12.2 for an image of the needle being introduced into the vein.

This may occur even in dynamic US placement as the angle of approach may take the needle out of the plane of the US transducer at the distal end of the vessel. It should be noted that IJV CVC placement still carries a significant risk of pneumothorax, particularly if the placement

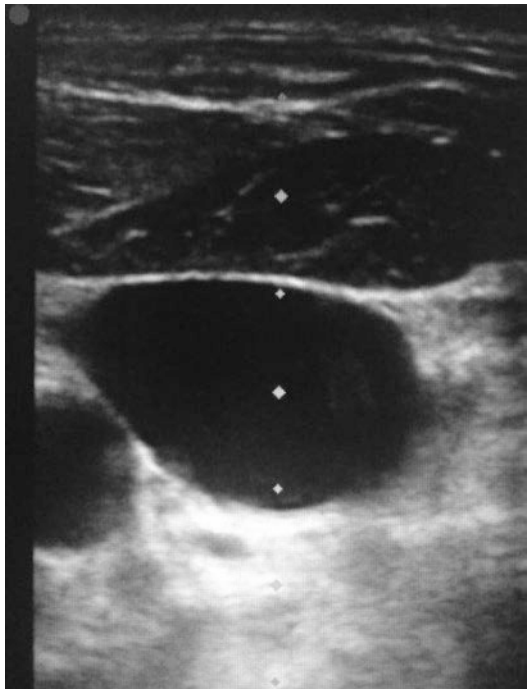

Fig. 12.1 Short-axis (SA) view of carotid/internal jugular showing compressibility of the IJ vein. (Courtesy of Ryan O'Gowan, MBA, PA-C, FCCM)

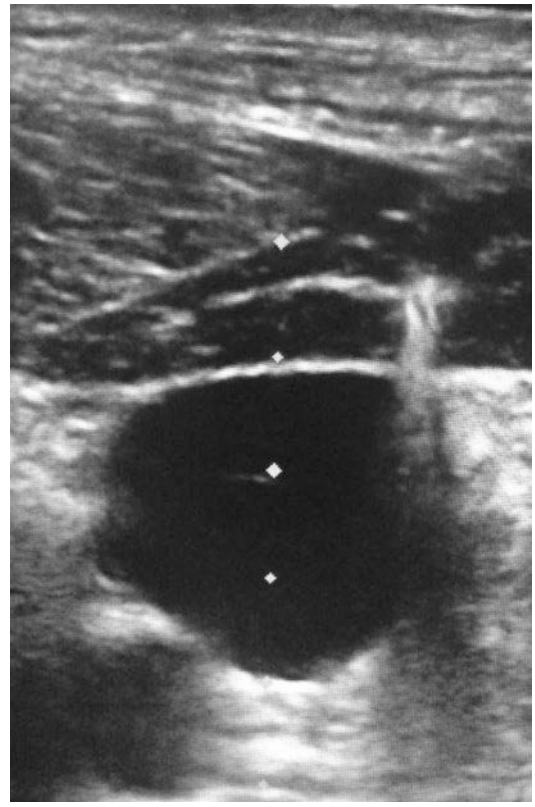

Fig. 12.2 Needle entering internal jugular on SA view using dynamic technique. (Courtesy of Ryan O'Gowan, MBA, PA-C, FCCM)

occurs on the lower third of the neck. A significant review of the literature revealed a paucity of information on the use of US in the SC site. Traditionally, operators may switch to a long-axis (LA) view (see Fig. 12.3).

However, one prospective, randomized crossover trial failed to show an attendant increase in the success rate in US-guided SC CVC placement [31]. This is likely due to a number of reasons, among them being the fact that anatomically the SC vein courses beneath the clavicle.

Complications

A number of factors may impact complication rates in the placement of CVC lines. In research conducted at Johns Hopkins, it was noted that although operator experience of less than 25 CVC lines did not impact success rates, complication rates were higher in inexperienced operators [32]. In a comprehensive review, a number of risk factors have been elucidated, with some of the more prominent being inexperience, number of needle passes (sixfold increase in complication risk with > three needle passes), BMI >30 or <20, large catheter size (i.e., hemodialysis access catheter), or prior operation and/or radiation exposure in the area of interest [6, 33]. Rare complications may include guidewire fraying, retention, or perforation of the vena cava. These complications, although rare, may require either median sternotomy or IR-guided retrieval of the retained wire [34].

One of the most feared complications is inadvertent dilation of a large arterial vessel. While accidental puncture of an artery with either a finder needle or introducer needle is generally not life-threatening, dilation may cause massive hemorrhage requiring operative repair. As such, it is prudent to discuss some measures that the operator may take to avoid this complication.

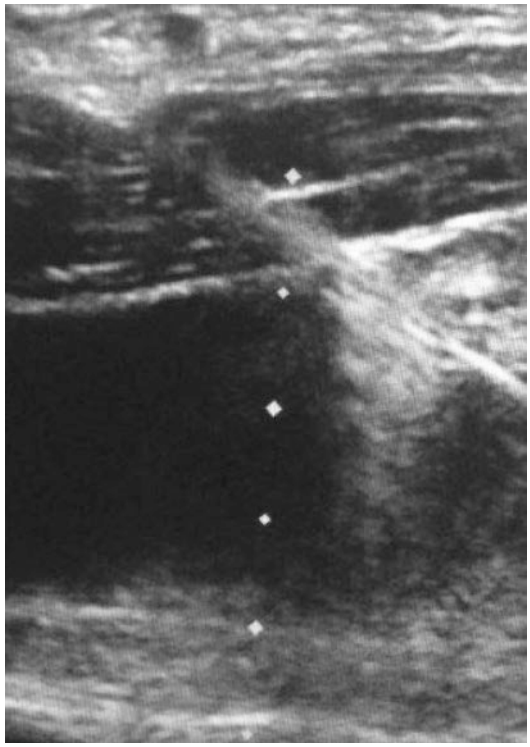

Fig. 12.3 Needle entering the vein on LA view. (Courtesy of Ryan O'Gowan, MBA, PA-C, FCCM)

First, dynamic ultrasound guidance has greatly reduced both inadvertent arterial puncture and subsequent dilation. As described above, operators are able to observe the introducer needle entering either the internal jugular or femoral vein in real time. In addition, many practitioners are now using ultrasound to confirm guidewire placement prior to dilation [35]. With this method, the guidewire is visualized in both the long and short axis to ensure it remains intravenous. Using this method of confirmation, intra-arterial placement was eliminated in one center [36]. Besides ultrasound, additional means of confirming the needle in the vein include utilizing a sterile length of IV tubing to transduce central venous pressure. In the case of arterial puncture, blood flow will not cease and will climb the entire length of tubing. In venous puncture, the blood flow may rise to a certain point and then cease. Significant respiratory variation of venous flow in the transducer tubing may signify hypovolemia or pneumothorax.

Table 12.3 Complications

Pneumothorax
Hemothorax
Chylothorax
Hematoma
Puncture of carotid, femoral, or subclavian artery
Vessel injury, including damage to SVC or aorta
Thoracic duct injury
CLABSI
Air embolism
Catheter fracture
Guidewire fracture
Retained catheter fragment
Retained guidewire

Common complications for CVC placement are outlined as follows in Table 12.3.

Process of CVC Insertion

The process of CVC insertion is best performed in a controlled environment. Clinicians are encouraged to use a pre-procedure checklist which facilitates safety and quality assurance. This provider's direct experience has been to perform the procedure with a minimum of assistance from other providers, who may be encumbered with other patient care activities.

The process is as follows for ultrasound-assisted placement of a CVC in the right internal jugular vein:

1. Obtained informed consent and discuss the risks and benefits of the procedure, as well as any potential complications. Ensure that the consent has the correct date and time. Also, if a phone consent is obtained, clearly print the name and telephone number of the consenting party. Document the type of relationship and have a witness verify and attest that you have thoroughly addressed the informed consent process.
2. Verify two forms of identification, typically patient name and date of birth. If the patient is intubated, verify with a second provider at the bedside. Also verify any allergies. Conduct a formal time-out process with the bedside nurse in attendance.

3. Gather necessary equipment including a mask and cap for each person remaining in the room during the procedure. Also gather the CVC kit, a gown, two pairs of sterile gloves, a sterile dressing kit, and sterile flushes.
4. Additionally, the ultrasound machine should be powered on and plugged in, should have the correct vascular access probe connected, and should have correct settings entered for depth and gain. A sterile probe cover should be obtained. At this point, it is prudent to inform the patient of the fact that you may be resting your hand on their jaw and that a drape will cover their face during the procedure. The author simulates this motion with the patient so that they understand their optimal body positioning throughout the procedure. A baseline ultrasound view is obtained of the internal jugular vein.
5. The bed is then placed in Trendelenburg position. If the patient has respiratory distress, this step can be deferred until after the draping process to minimize time in this position.
6. Using a skin marker, the operator marks their initials on the side of the body on which the CVC line will be placed.
7. The operator should thoroughly wash their hands for 60 seconds.
8. At this point, the operator opens the sterile equipment and dons the gown, along with two pairs of sterile gloves. The author proposes the cover glove system as it allows for more independent preparations. The outer gloves are typically one half size larger and may be shed after draping has taken place and after the ultrasound probe has been placed in the sterile probe cover.
9. Using chlorhexidine or betadine, cleanse the area in widening concentric circles and allow the cleansed area to dry. After drying, cleanse a second time, this time with a scrubbing motion. Ensure that not only the neck but also the landmarks which encompass the subclavian site are cleansed and draped so that the SC site may be used as a secondary insertion point should IJ insertion fail.
10. Drape the patient with a sterile sheet. Most commercially available kits contain a sterile drape with a clear area for patient visibility and a circular fenestration. Place this fenestration over the IJ site, ensuring that you do not drag any contaminated patient care bed linens into the sterile field which also encompasses the upper chest.
11. If assistance is available, have your assistant hold the ultrasound probe above the opening for the sterile probe cover, and using gravity, have them gently lower the probe into the probe cover. If no assistant is available, the operator may perform this piece independently and shed the outer cover glove after carefully placing the sterile probe cover/probe assembly on the field.
12. Draw up 5 cc of 1% lidocaine and infiltrate the soft tissues of the neck after gently aspirating the syringe.
13. At this point, organize the equipment on a sterile tray table in the order that it is used in the procedure. This ensures consistency of placement and assures an expeditious CVC placement. For junior operators, this assists them in acting as a type of prompt for the next step in the line placement process.
14. Using the provided sterile flushes included in the CVC kit, flush out all air from any attached claves, central line ports, or tubing.
15. Gently place the left hand with the probe perpendicular to the vessel in a short-axis view. Steady the thenar aspect of the hand on the patient's jaw. Ensure the view with the probe matches with the anatomic positioning of the vessels, with the carotid on the medial side and the internal jugular vein on the lateral side. Gently compress the vessel and center the vein in the middle of the screen.
16. With the bevel side up, position the right hand to bring the syringe into an acute angle. Maintain the needle into the plane of the ultrasound window. While steadily advancing the needle, look for a "V" indentation on the anterior wall of the vessel while continuing to gently aspirate. Continue to keep the needle in view of the ultrasound window. If the needle bevel disappears, stop advancing

with the right hand and slowly slide the left probe hand toward the base of the neck until the needle comes back into view. Once the needle is in the center of the vessel, continue to gently aspirate and drop the angle of the right hand to a shallower angle (approximately 30–45°). If using angiocatheter, advance catheter into vein.

17. Gently detach the syringe. If a sterile length of IV tubing is available in the kit, transduce and check blood flow.
18. Remove the tubing and introduce the guidewire. Monitor both length of guidewire and check for any dysrhythmias. Ensure that the guidewire is not put down at any time. Throughout the procedure, the operator may have to switch hands, but at no time should they put the wire down. Using ultrasound, verify the position of the guidewire in the vessel.
19. With the needle or angiocatheter still in place over the guidewire, gently nick the skin with the no.11 blade, with the blade side up. It is important to nick the skin with the needle covering the guidewire so that the wire is not inadvertently frayed by blade.
20. Remove the needle or angiocatheter, and advance the vessel dilator via Seldinger technique. Verify the dilator via ultrasound.
21. Remove the dilator and advance the catheter over the guidewire. Remove the guidewire and recover it into the guidewire sheath. This is in the event that the vessel needs to be recannulated for any reason. Additionally, the guidewire may potentially contaminate the field if left out.
22. Suture the catheter in position and flush all three ports with sterile saline.
23. Place a sterile dressing, and mark the date and time on the dressing. Verify the needle and sharps counts with the bedside nurse.
24. Place an order for a post procedure chest x-ray to verify the CVC line position.
25. Provide the patient/bedside nurse with education on CLABSI prevention. The CDC FAQ sheet may be found online at http://www.cdc.gov/hai/pdfs/bsi/BSI_tagged.pdf.
26. Document the procedure note, and document any medications given, number of attempts, complications, and results of post-procedure chest x-ray. Write an order allowing the nurse to use the CVC line, and maintain a relevant operator procedure log which documents site, side, number of attempts, and complications.

Conclusions

CVC placement is a procedure which is conducted ubiquitously in a variety of critical care settings. US guidance greatly increases the likelihood of operator success. That being said, complication rates in junior operators with less than 25 line placements may still be common. Operators with <25 prior insertions cause more complications (25.2% vs. 13.6%, $P = 0.04$), require the assistance of a senior operator more frequently, and have more completely failed attempts [37]. Best practices and good judgment should be utilized in the placement of CVC catheters, and junior operators 25–50 line placements have higher success rates (90% versus 75%) when supervised by a more experienced operator, with a lower interim complication rate using US. Senior operators responsible for the training of individuals should utilize a number of strategies including web-based didactics, simulation, physical supervision, and frequent review of procedural logs [27–29, 37]. Ultrasound guidance, particularly for the internal jugular site, is encouraged as it reduces complications in both new and experienced operators. With experienced operators, in the event that no US machine is available, the subclavian or femoral site may still be a safe alternative [23]. Although many studies have addressed the difference in complication rates among learners of various experience levels, some data with regard to physician assistants versus physicians show that well-trained physician assistants have comparable complication rates when conducting invasive procedures [38, 39].

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Hemodialysis Catheter Insertion

13

Brandon Oto and Christopher L. Atkins

Introduction

A common procedure in the critical care setting is the insertion of large bore, double-lumen central venous catheters (CVCs) into deep veins. While similar in many respects to other central lines, these devices differ in several important ways, particularly their application, which is generally for temporary hemodialysis and other blood exchange therapies (Fig. 13.1).

Although the non-tunneled, temporary hemodialysis catheter (NTHC) is often referred to using brand names and other colloquialisms (Box 13.1), such catheters are nothing more than specially designed CVCs with specific key features:

1. *Size*: Unlike ordinary CVCs placed for medication delivery or blood draws, which typically have an external diameter of 7–8 French, NTHCs are often 12 French or larger.
2. *Configuration*: Rather than containing numerous small internal lumens (cf. the ubiquitous triple-lumen catheter), NTHCs have two large lumens, with maximal diameters to allow brisk blood flow. Although both lumens terminate in the venous system, a more proximal "venous" side is intended for inflow, while a distal "arterial" side is used for outflow; the outlet ports are staggered or separated to reduce mixing and recirculation during dialysis. Additional, smaller "pigtail" lumens may also be present and are usually used for medication infusions.

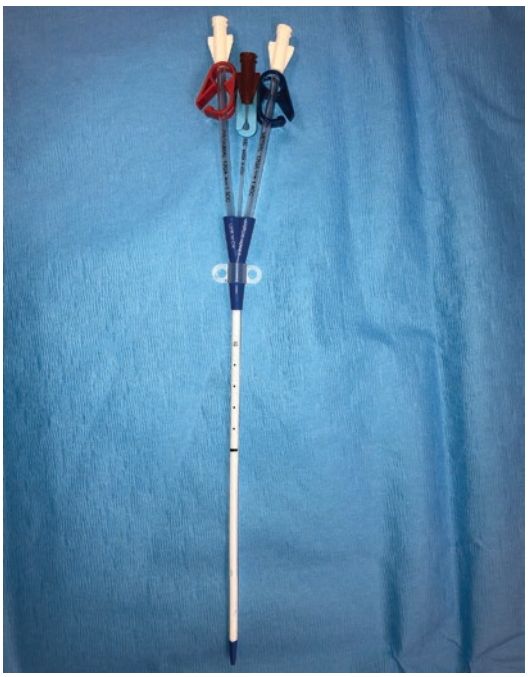

Fig. 13.1 Typical NTHC with a third "pigtail" lumen

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3. *Technical considerations of placement*: While the core principles of placement are identical to other CVCs, the larger size of these catheters creates a greater demand for correct, error-free technique.

Box 13.1 Common Institution-Specific Colloquialisms for Temporary, Non-tunneled Hemodialysis Catheters

- Vascath
- Quinton
- Hema-Cath
- Mahurkar
- Udall
- "Permacath" (easily confused with tunneled lines)
- Medcomp
- Trialysis
- Shiley
- Niagra
- GamCath

As many of these terms are easily confused with other devices, their use is not recommended.

Indications

Unlike other CVCs, NTHCs are placed for one of several discrete clinical scenarios:

1. *Temporary hemodialysis*: The most common application is in the critically ill patient with acute kidney injury and an indication for urgent or emergent renal replacement (Table 13.1). This can later be transitioned to more permanent access if renal recovery does not occur.
2. *Rescue hemodialysis*: Patients with baseline renal failure occasionally present with failure of their existing dialysis access, requiring placement of a temporary catheter, while arrangements are made for either salvage of the access or placement of new access.
3. *Plasmapheresis*: Although distinct from hemodialysis, plasma exchange is performed in a similar manner and requires similar venous access; it is an infrequently used but important therapeutic modality in clinical scenarios such as thrombotic microangiopathies (e.g., TTP).
4. *Large-volume resuscitation*: Similar to introducer sheaths ("Cordis" catheters), NTHCs are an effective access choice when high volumes of blood or other fluid need to be rapidly infused, such as for major trauma, GI bleeding, or obstetric hemorrhage. Due to their length and additional lumens, they tend to be more versatile than introducer sheaths, which in the most basic form offer only a single, short lumen for infusion.

Table 13.1 Indications for urgent or emergent renal replacement therapy

*A*cidosis
*E*lectrolyte abnormalities (typically hyperkalemia)
*I*ntoxication with dialyzable substances
Fluid *O*verload
*U*remia with clinical sequelae such as encephalopathy, pericarditis, or platelet dysfunction

Easily remembered using the mnemonic *AEIOU*

Contraindications

As with other emergent vascular access, there are few absolute contraindications to NTHC placement. Relative contraindications should be weighed against the clinical benefit and can often be managed by alterations in technique (Table 13.2). Subclavian vein placement is typically contraindicated if other sites are available (see section "Complications"). Finally, NTHCs should not be placed if their intended application, such as dialysis, is not consistent with the patient's goals of care.

Table 13.2 Relative contraindications for NTHC placement

Coagulopathy
Presence of an AICD or pacemaker (for IJ or subclavian sites)
Known thrombosis or venous stenosis proximal to the insertion site
Inability to tolerate a supine position (for IJ or subclavian sites)

Risks/Benefits

Risks of NTHC placement resemble those with other vascular access.

- Bleeding
- Thrombosis or stenosis
- Infection
- Injury to other structures (arteries, nerves, or lung injury resulting in pneumothorax)
- Air embolism

Benefits are determined by the indication, and alternatives are typically few. Unlike other CVCs, which can sometimes be avoided, there are usually no therapeutic alternatives to NTHC placement for unstable patients requiring emergent hemodialysis (e.g., for refractory hyperkalemia). Occasionally, medical therapy alone can be successful, and in exceptionally rare circumstances, peritoneal dialysis may be attempted.

Preparation

1. Obtain informed consent, unless precluded by emergent circumstances.
2. Real-time ultrasound guidance has been shown to improve both procedural success and complication rates and is strongly recommended where available [1, 2]. Using ultrasound, begin by inspecting the vessels to determine the optimal site for placement. The target vein should be patent, large-bore, and accessible without puncturing an overlying artery; its true location may vary significantly from that predicted by anatomical landmarks [2]. Since CVC placement in femoral vessels has been inconsistently associated with an increased risk of CLABSI (with particular risk in the obese population) [3–5], the neck veins are usually preferred, although the femoral site may be first line in patients with a high bleeding risk. If a permanent surgical access is present on one arm, IJ access on that side is relatively contraindicated. Patient factors being equal, site preference is as follows:
   (a) *First choice*: Right IJ. The optimal puncture site is ordinarily near the clavicle, between the two heads of the sternocleidomastoid muscle (Fig. 13.2).
   (b) *Second choice*: Left IJ. Flow is typically slower, and the vessel smaller and more tortuous compared to the right.
   (c) *Third choice*: Femoral veins. (Some sources favor the femoral veins over the left IJ [6].) The right femoral vein is straighter and may be slightly preferred over the left. The common femoral vein is usually accessed, although ultrasound guidance sometimes permits more distal placement in the superficial femoral (Fig. 13.3).

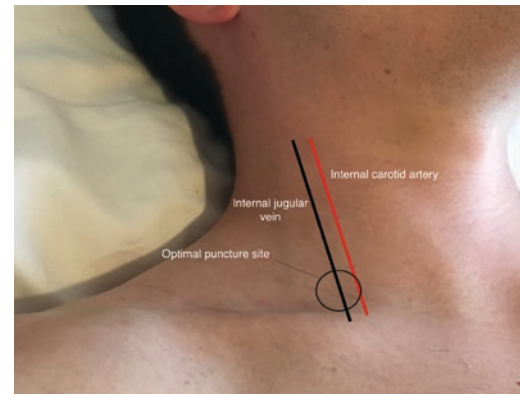

Fig. 13.2 Optimal puncture site for the right IJ site

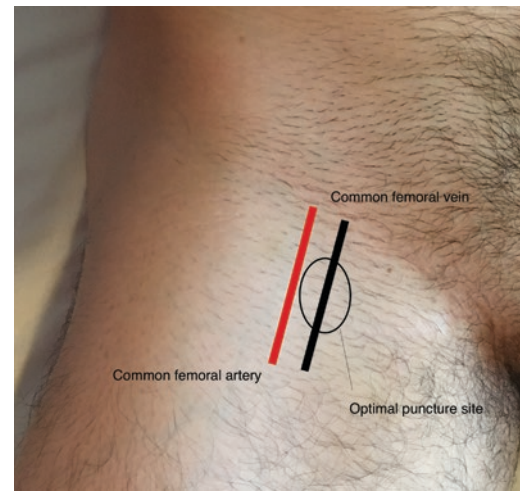

Fig. 13.3 Optimal puncture site for the right femoral site

(d) *Last choice*: Subclavian veins (which present a high risk for stenosis in this setting) or other vessels (trans-lumbar IVC access, hepatic veins, etc.), the latter of which typically require specialist placement in the IR suite. The external jugular veins can also sometimes be cannulated with good results [7].

3. Prepare the room. The bed should be positioned at a comfortable height. For IJ placement, the head of bed should be lowered as much as tolerated (into Trendelenburg if possible), barring contraindications such as an elevated intracranial pressure. For femoral placement, the head of bed should be flat or slightly elevated. The operator should stand behind or adjacent to the head of the bed for an IJ. For femoral lines, stand at the mid-bed; many right-handed operators prefer to stand at the patient's right side regardless of site laterality. Position a large table and trash receptacle nearby. The ultrasound machine should be positioned across from the operator, with image settings already optimized for vessel visualization.
4. Perform a time out, verifying patient identity, consent, allergies, and relevant clinical details such as platelet count and coagulation studies. Ensure the presence of a skilled assistant to perform non-sterile activities and monitor the patient.
5. Prepare the field, removing foreign objects such as gowns, wires, and linens. Place a barrier sheet beneath the patient to catch blood and other debris. If body hair is ample at the site, it should be trimmed, ideally using electric clippers. Grossly dirty skin should be cleaned using soap and water. Tape is sometimes needed to pull apart skin folds.
6. Don a hat and mask. Any other personnel in the room should follow suit.
7. Clean the site using chlorhexidine, using a scrubbing motion to prepare a wide area. A 30-second prep is used for clean skin, or 2 minutes for moist or soiled areas. Allow chlorhexidine to fully dry before performing any skin punctures (Fig. 13.4).

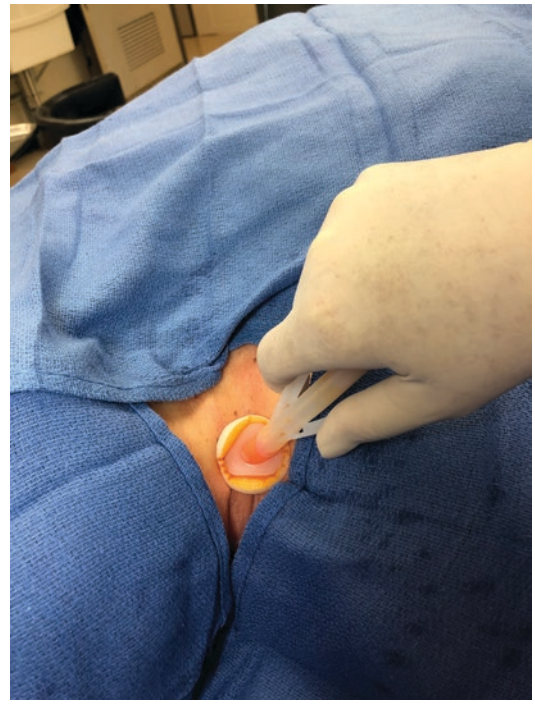

Fig. 13.4 Preparing the skin

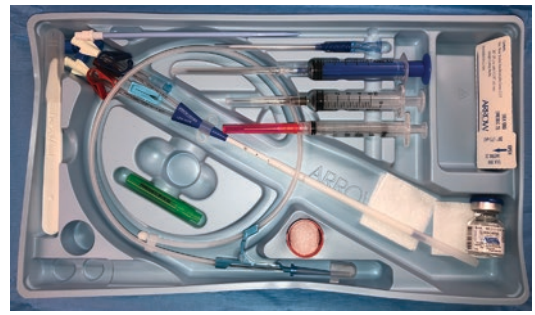

Fig. 13.5 The opened kit

Procedure

1. Open the kit, and drop any separately packaged items into the field using aseptic technique (Fig. 13.5).
2. Don a sterile gown and gloves (Fig. 13.6).
3. Drape the site with a fenestrated sterile drape, preferably one large enough to completely cover the bed. (In awake patients, this can be deferred until just before skin punc-

Fig. 13.6 The operator in full sterile gown, gloves, hat, and mask

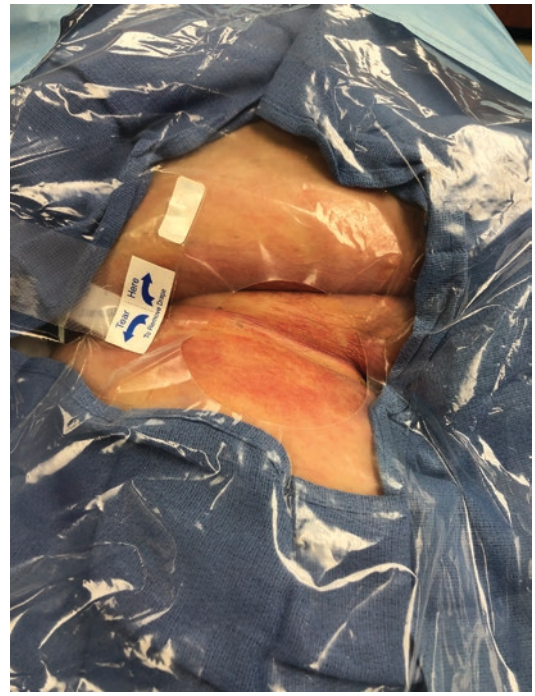

Fig. 13.7 The femoral site draped and exposed

ture, as prolonged draping can cause claustrophobia.) (Figs. 13.7 and 13.8).

4. Prepare the kit. Flush all lumens of the catheter, and lock all lumens except the most distal port. Uncap the wire and retract the J-tip. Draw lidocaine into a syringe, and attach a small-gauge needle for infiltration. If using ultrasound, place a sterile probe cover over the transducer. The wire, gauze, and other items (if desired) can be positioned securely upon the draped bed. Load the introducer needle onto a slip-tip syringe, with the bevel aligned with the syringe markings to help maintain a bevel-up orientation of the needle during entry (Figs. 13.9 and 13.10).
5. Apply the ultrasound to the site using sterile gel and relocate the vessel, identifying the exact point of skin puncture and noting the position of the nearby artery. Topical anesthesia is best performed in two steps:
   (a) Using the smallest available needle in a flat plane, barely break the skin at the desired puncture site. Raise a wheal of lidocaine here, as well as adjacently to either side, where sutures will later be placed. Remove the needle (Fig. 13.11).
   (b) If available, attach a longer small-gauge needle. Using a more acute angle, puncture the skin at the site of the previous wheal. Under continuous aspiration and real-time ultrasound guidance, follow the needle down to the vessel as if attempting to access it. Every few millimeters, inject a small aliquot of lidocaine to numb the subcutaneous tract.

Fig. 13.8 Sterile drape fully opened

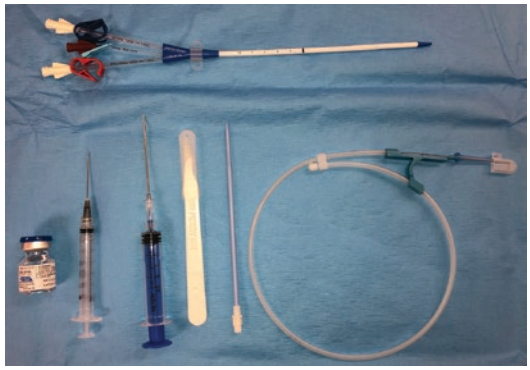

Fig. 13.9 Key tools for accessing the vessel. Top: catheter. From left to right: lidocaine and small-bore needle on Luer lock syringe (for local anesthesia); introducer needle on larger slip-tip syringe (in this case a Raulerson syringe); scalpel; dilator; and guide wire

Fig. 13.10 Covering the probe with a hand-in-sheath technique

When the edge of the vessel is reached, inject along its border and then remove the needle. (If the vein is inadvertently punctured, the needle can simply be withdrawn.)

6. Make the final skin puncture using the introducer needle. Hold continuous aspirating pressure on the syringe once the skin is breached. Using small, methodical, intermittent movements, alternate between advancing the needle toward the 12 o'clock position of the vein and advancing the probe to maintain visualization of the needle tip (Fig. 13.12).
7. As the needle breaches the vessel, a flash of blood will enter the syringe. The needle can then be lowered to establish a flatter angle for wire introduction. With every change in position, aspirate blood to confirm the needle tip remains intravascular.
8. Stabilize the needle using the offhand to prevent dislodgement. Remove the syringe.
9. Insert the guidewire, which should pass without resistance. Orienting the J upward will allow a smoother initial entry. Place the wire to approximately the same depth as the eventual catheter length (usually 15–20 cm). Once in place, the wire should remain immobile to act as a guide rail; pinch the exposed wire to anchor it during all maneuvers (Figs. 13.13 and 13.14).

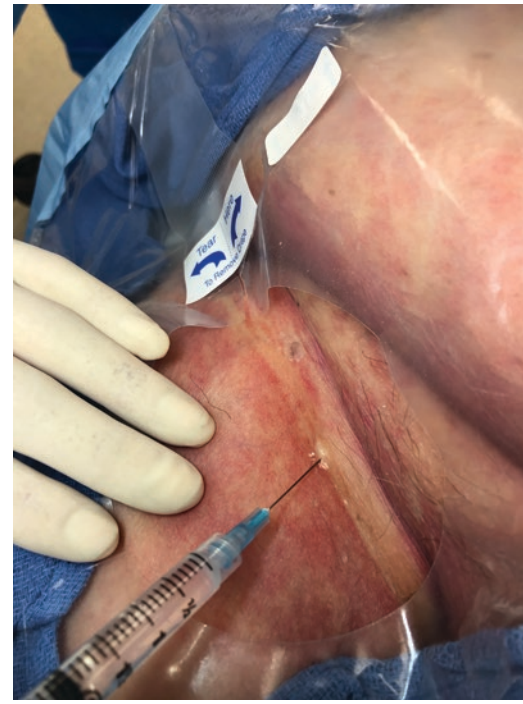

Fig. 13.11 Infiltrating lidocaine superficially for local anesthesia. Note the flat needle angle and visible wheal

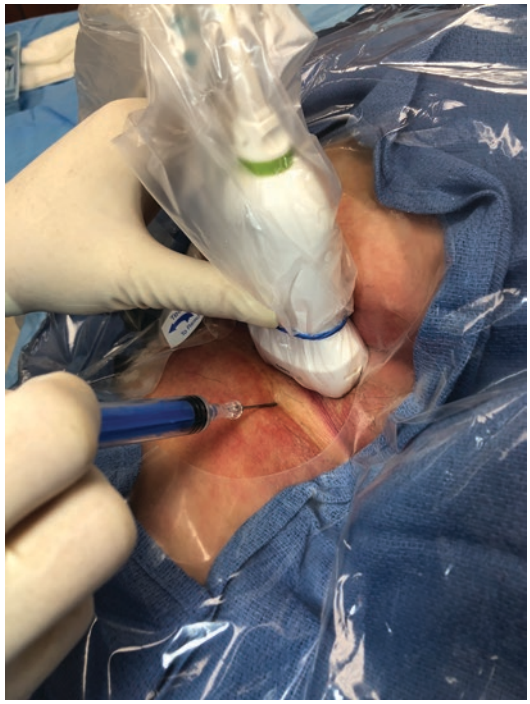

Fig. 13.12 Accessing the vessel with the introducer needle and out-of-plane ultrasound guidance. Note the square angle between needle and probe and a grip on the syringe which allows continuous aspirating pressure on the plunger

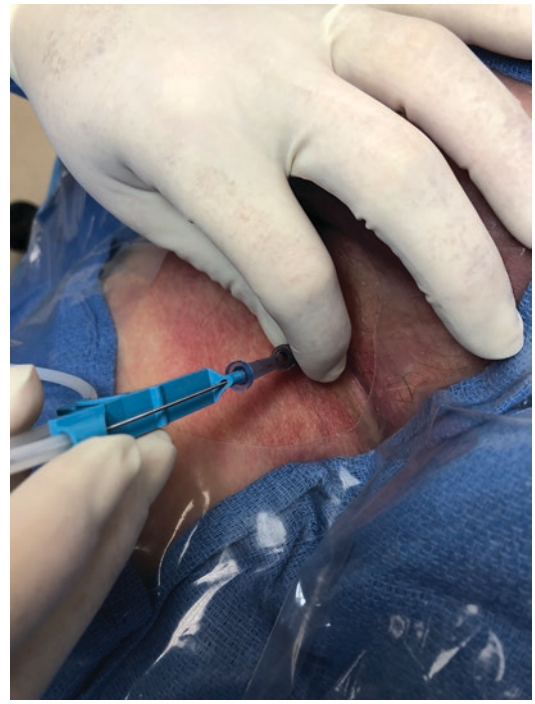

Fig. 13.13 Stabilizing the needle and inserting the wire

10. Remove the needle over the wire.
11. If there is any doubt as to whether a vein or an artery was accessed, confirm venous placement before proceeding with dilation (Box 13.2).
12. Make a small skin nick by sliding the non-cutting back edge of the scalpel against the wire into its same hole, creating a stab incision, just deep enough to enter the skin. Ensure that the nick has expanded the initial hole rather than creating an adjacent one. (In coagulopathic patients, the skin nick can sometimes be omitted.) (Fig. 13.15).
13. Insert the dilator over the wire. Begin dilating the skin and subcutaneous tissue with firm, steady forward pressure on the dilator, held just above where it enters the skin. Maintain traction on the wire with the off-hand (Fig. 13.16).
14. Remove the dilator. Bleeding will occur from the puncture site; hold pressure with gauze.

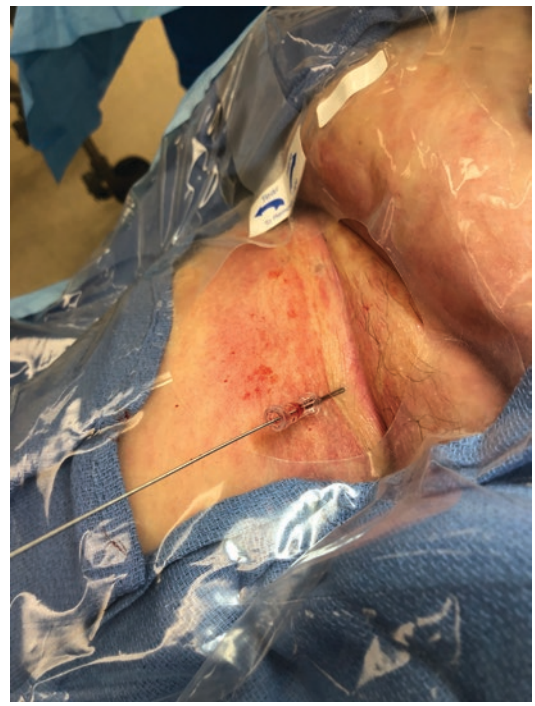

Fig. 13.14 The guide wire in place

Box 13.2 Methods of Confirming Intravenous Position

Venous blood is typically darker than arterial blood, lower in pressure, and much less pulsatile when allowed to flow freely. However, these guidelines are not always reliable. When in doubt, one of the following methods should be used for confirmation prior to dilation:

- *Fluid column manometry*: Our preferred technique. An angiocatheter is inserted over the wire and then attached to a length of IV tubing, which fills with blood via gravity. Holding it upright creates a column manometer, allowing passive transduction of the vascular pressure in centimeters of water. A column height consistent with a normal CVP (<20 cm above the right heart), with respiratory phasicity but no arterial pulsation, is reassuring for venous placement.
- *Flush test*: The angiocatheter can also be flushed with saline, while an assistant visualizes the right heart using cardiac ultrasound. Venous placement is confirmed by the rapid appearance of bubbles in the right atrium.
- *Vascular ultrasound*: Direct B-mode ultrasound visualization, showing the wire inside the vein without penetration of the artery, is a rapid but less definitive technique.
- *Differential blood gasses*: Simultaneous blood gasses drawn from the puncture site and from a known arterial source can be compared to demonstrate a difference in pH and gas tension. This method is cumbersome and generally unnecessary.

If arterial puncture is discovered, the needle or wire should be removed, and direct pressure held for 5–10 minutes to prevent the formation of a hematoma or pseudoaneurysm.

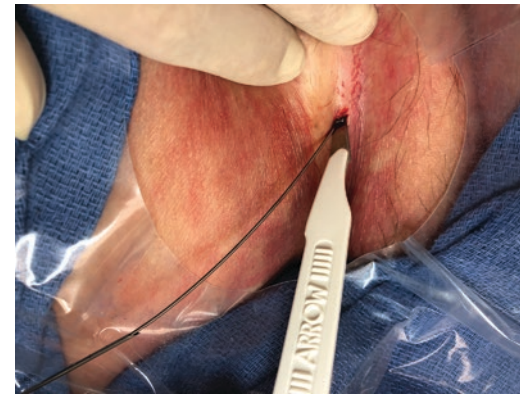

Fig. 13.15 Widening the hole with a small "plunge" scalpel incision

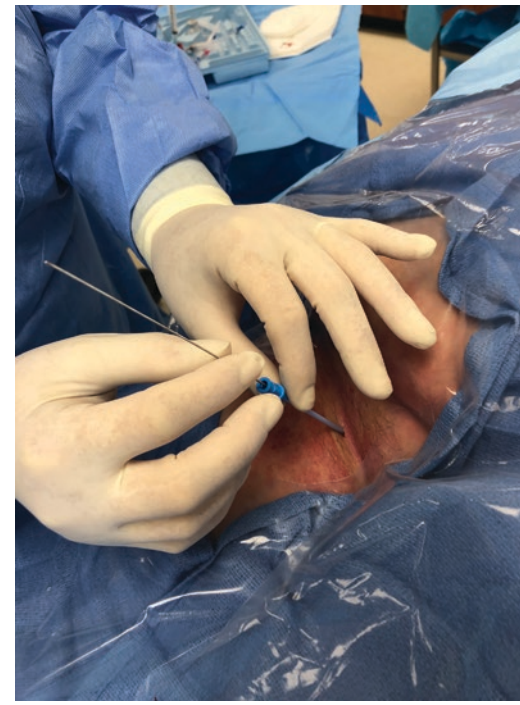

Fig. 13.16 Dilating the skin. An overhand grip close to the tip should be used (the hand is positioned more proximally in this image for visual clarity)

15. Insert the next largest dilator and repeat. This process is repeated for each available dilator (from 1 to 3 steps depending on the kit).
16. After the final dilation, railroad the catheter over the wire and insert it to the desired depth, which should be the same as for routine CVC placement (Box 13.3). Maintain a

Box 13.3 Approximate Catheter Insertion Depths

- Right IJ: 16 cm
- Left IJ: 18 cm
- Femoral vein: 20–25 cm

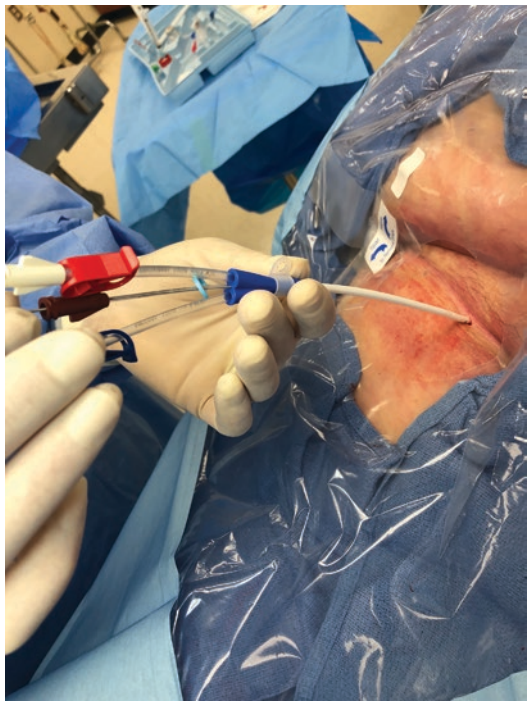

Fig. 13.17 Inserting the catheter

continuous grip on the wire to prevent its loss (Figs. 13.17 and 13.18).

17. Leaving the catheter in place, remove the guidewire.
18. Attach a syringe to each lumen and unclamp it. Use firm pressure on the plunger to aspirate blood and then return it several times, confirming *brisk* flow with minimal resistance. If flow is sluggish, the catheter must be repositioned (Box 13.4). Keep the syringe upright with the rear (plunger) end elevated to avoid flushing in air bubbles, which tend to develop during this process.
19. Flush each port with saline or heparin, per local protocol. Clamp the lumen while flushing. Cap any pigtail ports with a Luer lock

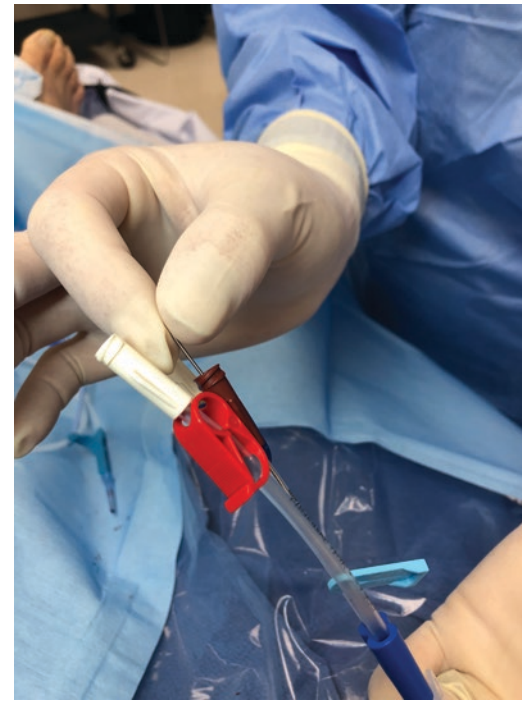

Fig. 13.18 The offhand should continuously secure the proximal end of the wire during dilation and catheter insertion

Box 13.4 Troubleshooting When Flow Is Poor

When a port aspirates successfully, but only intermittently or sluggishly, several maneuvers can be attempted.

- *Depth adjustment*: One of the lumen outlets may be lying against a vessel wall or valve, in which case withdrawal may improve flow; conversely the tip may not have reached a sufficiently central and high-flow location and may benefit from advancement. Catheter depth in centimeters (Box 13.3) is a rule of thumb that guides initial insertion, but flow adequacy is the ultimate proof of optimal positioning.
- *Rotation*: Withdrawing the device several centimeters and rotating it while readvancing may improve flow by situating the outlets at different angles.

- *Volume loading*: In a hypovolemic patient, flat vessels may collapse and occlude the catheter during application of negative pressure. (This is uncommon in renal failure that occurs over days, as such patients tend to be volume overloaded, but can occur in fulminant renal failure or in hemorrhagic shock patients.)
- *Correction of placement*: Verification of tip placement intra-procedurally (via chest x-ray with rapid digital processing, or by echocardiography) can confirm catheter position in the SVC rather than unintentional diversion into an innominate vein or other vessel.

clave. Dialysis lumens can be covered with regular caps, which will be removed for hemodialysis.

20. Position any external catheter slack to permit application of an adherent dressing away from the face or hair. Tight bends will limit flow, but IJ lines can usually be pointed laterally and dressed onto the supraclavicular fossa.
21. Suture the hub to the skin. (If distant to the original puncture site, the skin here should first be infiltrated with lidocaine.) In some institutions, sutureless adhesive devices are an alternative option and can be particularly useful in coagulopathic patients (Fig. 13.19).
22. Clean the entire site, including the skin and all surfaces of the hardware. Use moist gauze to remove blood, followed by a fresh chlorhexidine applicator. Allow the chlorhexidine to dry.
23. If used in your institution, place a chlorhexidine-impregnated patch over the puncture site. (Some dressings contain their own an antibiotic patch, obviating the need for this.)
24. Paint an adhesive skin prep, such as tincture of benzoin, on the skin around the catheter. Prepare a space matching the dressing that will be placed.

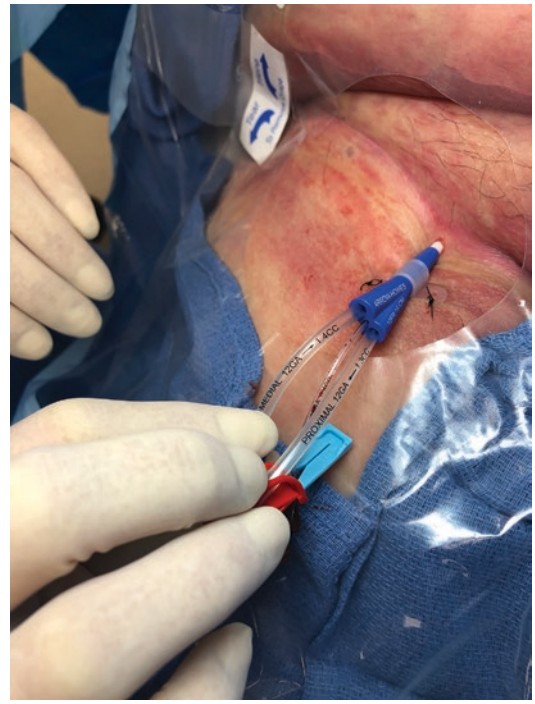

Fig. 13.19 The catheter is secured by two sutures at the hub

25. Apply an occlusive transparent dressing, which should cover both the puncture site and the sutures. In patients with persistent bleeding or serous oozing from the site, a gauze dressing should be used instead and changed by nursing once soiled. Date and initial the dressing (Fig. 13.20).
26. Confirm IJ catheter location and absence of pneumothorax by portable chest x-ray, preferably captured in a semi-recumbent or upright position. The catheter tip should ideally overshadow the cavoatrial junction. (If digital point-of-care x-ray viewing is available, this step can be performed prior to placement of the sutures and dressing, allowing immediate adjustment of a malpositioned catheter.)
27. Remove the drape and discard used supplies, safely disposing of all sharps. Document the procedure in the medical record, including the number of attempts, any complications, and the depth of catheter placement.

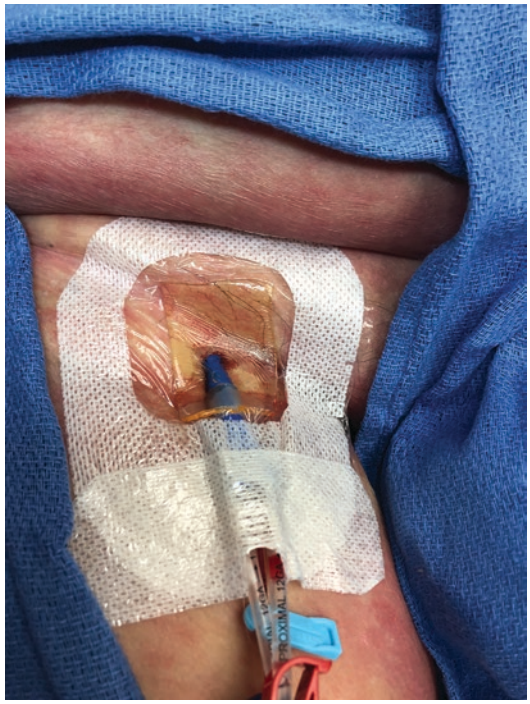

Fig. 13.20 A clean, fully adhered, occlusive dressing

Complications

Complications after NTHC placement largely reflect those of central line placement. However, their larger diameter does present an increased risk of mechanical complications. Unlike a typical 7 French triple-lumen catheter, NTHCs may have external diameters as large as 14 French, which presents a proportionally greater risk of bleeding and thrombosis.

Although these large veinotomies usually bleed transiently with dilation, they are generally well-sealed after placement of the catheter. Catheter *removal*, however, should be undertaken with care, with prolonged administration of direct pressure (a minimum of 5–10 minutes without interruption); particular care and prolonged pressure is needed in the presence of anticoagulation or coagulopathy. Unplanned catheter removal caused by snagging or patient manipulation requires the emergent provision of direct pressure, as exsanguination can otherwise occur [8].

Substantial morbidity is associated with inadvertent arterial placement. Arterial puncture with an introducer needle alone is generally tolerated after a period of direct, non-occlusive pressure. If dilation has been performed, however, a 12–14 French arteriotomy cannot be closed with pressure alone and portends a high risk of major hemorrhage. This is best avoided by cautious confirmation of venous placement prior to dilation (Box 13.2). If large-scale dilation of an artery has been performed, immediate consultation with a vascular surgeon is advised, with any indwelling catheter *left in place* rather than removed. Open surgical repair may be needed.

Tissue injury caused by the catheter tip, such as erosion of heart valves or chamber walls, is a theoretical possibility. While this risk is probably higher with placement of an NTHC than a smaller line, it remains exceptionally rare and probably less likely with the modern generation of devices that are more flexible and less traumatic [9]. Catheter tips that lie in the right ventricle or within the tricuspid valve should be withdrawn, whereas right atrial placement is usually safe (and indeed may improve flow). We generally tolerate catheter tips within the upper IVC or innominate vessels if flow is good, except left IJ catheters whose tip directly abuts the SVC wall; these should be repositioned to allow a more parallel tip orientation.

An important complication in the setting of renal insufficiency is the risk of venous stenosis after catheter placement. This can occur in any vessel but is especially clinically important when a large-caliber catheter is placed in a subclavian vein, since stenosis there can limit flow from the ipsilateral extremity—potentially excluding later placement of surgical dialysis access in that limb [10]. Since patients requiring temporary hemodialysis are obviously at risk of requiring long-term dialysis, whenever possible, the subclavian vein should be avoided. When surgical dialysis access is already present in an upper extremity, ipsilateral IJ catheterization is also relatively contraindicated, as it may reduce access survival [11].

As with any central access, air embolism can occur during placement, and risk is probably

increased with NTHCs to their larger lumen size. (Although the high CVP in many volume overloaded patients may reduce this risk, the occasional need to perform the procedure with the head elevated can conversely increase it.) In such cases, particularly in spontaneously breathing patients with vigorous respiratory effort, scrupulous precautions are required to prevent air entrainment; this includes digital occlusion of open ports, immediate clamping and capping after catheter flushing, and possible use of a Raulerson syringe for the initial vessel puncture. A well-developed subcutaneous tract can also persist after catheter removal, and the puncture site should be dressed with an occlusive transparent dressing rather than gauze alone.

The risk of catheter-associated bloodstream infection with NTHCs generally resembles that with other CVCs, although it may be slightly higher per catheter-days [12]. It should be mitigated using similar strategies, including stringent sterility during insertion and removal. The best strategy for infection prevention is early catheter removal. Although NTHC colonization rate does increase linearly over time, there is no specific cutoff duration for dwell time when placed in the acute setting; rather, they should be removed promptly when either renal recovery occurs; it becomes clear that the patient will require long-term access, or signs of infection or other line complications develop.

Keys to Success, Perils, and Pitfalls

In general, NTHC placement should be approached as central line placement, except to a higher degree of stringency. Although most procedural steps are technically similar, tolerance for error is less. If excellent and stringent technique is universally used, central catheters of any size can be placed in a virtually identical manner.

Nowhere is this more important than during dilation. Dilators in NTHC kits are significantly thicker and longer than dilators for other catheters, yet the wires are rarely stiffer. Particularly when accessing deeper vessels (such as the femoral vein in obese patients), this can predispose to wire kinking during dilation, a vexing problem that often requires opening a fresh wire.

Kink prevention starts during the initial needle puncture, which as much as possible should be performed upon a fixed angle. Large changes in direction, whether deviations in angle of attack or lateral "steering" to align with the vessel, establish a tortuous and non-sustainable wire path. While the stiff needle can initially maintain a straight line, once the needle has been removed the tissue will spring back into place, creating a circuitous wire course that is easily kinked by the straight dilator.

Dilation should also follow the same path as the needle and wire—inserted at the same angle and terminating at approximately the same depth. Changes in angle between wire and dilator create kinking, overpenetration can injure the vessel, and underpenetration results in inadequate dilation, which can make the catheter difficult to place. With every push of the dilator, the wire should be racked back and forth to demonstrate free movement; if it does not easily withdraw, this indicates it has begun to kink, and the dilator path should be corrected to prevent worsening the kink. A two-handed method of short, brisk, continuous racking during dilation may be the safest approach, although it sometimes requires assistance.

With large catheters, dilation is not complete until the vessel itself has been dilated. Visualizing a small "flash" of blood around the wire at the proximal end of the dilator can be a useful indicator that the vessel has been successfully reached.

Vascular insufficiency, such as stenosis, occlusion, or tortuosity, can also create intraprocedural difficulties. Patients requiring acute hemodialysis are often vasculopathic and may have one or more deep veins that prove to be poor substrate for catheter placement. The vessel should always be inspected beforehand for patency using ultrasound. However, if difficulty is encountered advancing the wire or catheter, a more proximal vascular obstacle is probably present, and there should be a relatively low threshold for aborting the attempt in favor of a different vessel.

CPT Coding

Coding for non-tunneled hemodialysis catheter placement is identical to other central lines. 36556 should be used for patients >5 years of age, or 36555 for patients <5 years. If ultrasound was used to evaluate the site—to confirm vessel patency and for *real-time* needle guidance, with visualization of the needle tip intravascularly—76937 can be billed as well; however, this requires that an image be recorded and permanently stored.

Summary

NTHC placement is an important bedside procedure in the ICU that shares many of its principles with insertion of other CVCs, such as sterile technique, Seldinger methodology, and the growing use of ultrasound guidance. However, specific considerations set it apart, including the need for brisk blood flow, and an increased risk of complication due to large catheter diameter. A thoughtful approach and excellent procedural technique are needed to maintain this procedure as a safe, foundational cornerstone of modern critical care.

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Additional Resources

National Kidney Foundation Kidney Disease Outcomes Quality Initiative (KDOQI) Clinical Practice Guideline for Hemodialysis, 2015: https://www.kidney.org/professionals/guidelines/hemodialysis2015.

Intraosseous Access Techniques

14

Ryan P. Bierle

Introduction

Clinicians commonly face frustration when working to gain access to a patient's circulation during emergency situations. Frequently, traditional attempts to establish peripheral intravenous access are complicated by the decreased venous flow seen in patients in shock or cardiac arrest. Consequently, clinicians are often compelled to access larger veins through blind or ultrasound-guided central venous catheterization, a procedure which carries a significant risk of serious complications and is time-consuming. However, intraosseous infusions offer a safe and rapid alternative method of vascular access during emergent resuscitations.

As early as 1922, the concept of utilizing the intraosseous space for vascular access and infusion was first proposed, with the marrow being described as a "non-collapsible vein" [1]. The medullary sinuses of the long bones drain into veins that return to the central circulation (Fig. 14.1). These veins remain patent during shock due to the support from the bony matrix (Fig. 14.2). Initially, intraosseous infusions were reserved for infants and children. Increasingly, the technique is being utilized in adult patients presenting with medical or traumatic shock. Intraosseous infusion for emergent vascular access is now recommended and taught during numerous training programs including Advanced Cardiac Life Support, Advanced Trauma Life Support, Pediatric Advanced Life Support, and Tactical Combat Casualty Care [2, 3].

Indications

Intraosseous access is indicated in patients who are unlikely to have traditional vascular access initiated in a safe or timely manner. The most typical indication is during cardiac arrest and cardiopulmonary resuscitation [3]. However, there are numerous other patient presentations that benefit from the rapid access intraosseous infusion offers. These include circumstances when the patient is medically unstable such as multisystem trauma or septic shock. Additionally, it may be considered during situations when the medical condition precludes conventional intravenous access for the safety of the patient and healthcare workers (excited delirium, status

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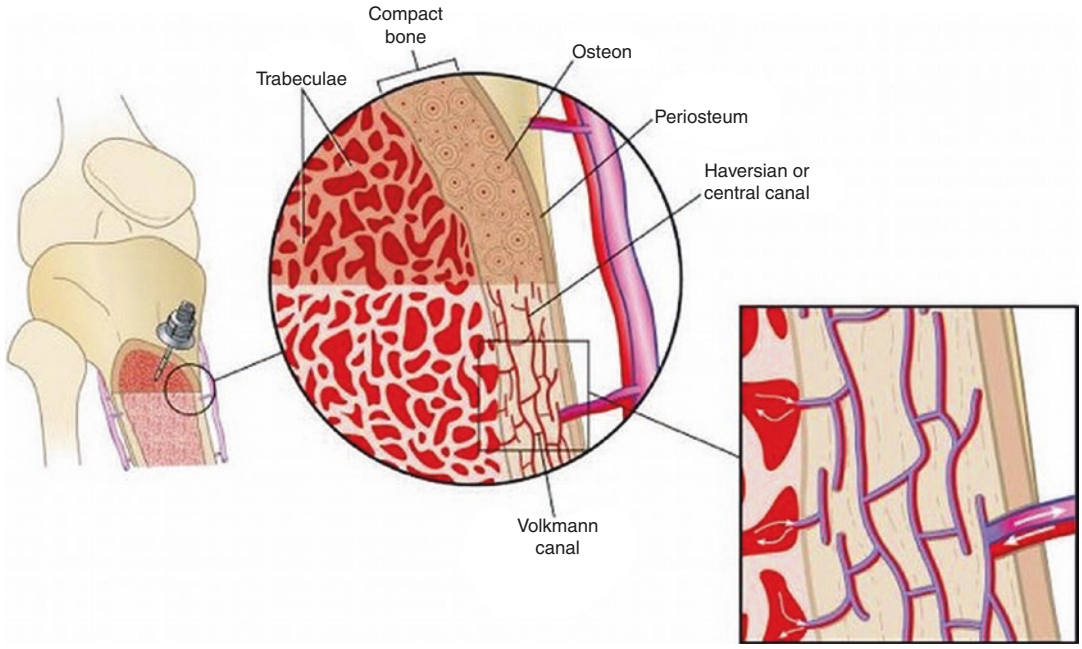

Fig. 14.1 IO anatomy

Fig. 14.2 IO bony matrix

epilepticus, confined space rescue). Frequently, intraosseous access is not attempted until multiple intravenous access attempts have been unsuccessful. Yet, intraosseous placement first-pass success rates are as high as 97% in less than a minute. An experienced clinician will recognize patients in which intravenous access is unlikely to be successful and initiate intraosseous access early in the resuscitation [2, 4].

Once the clinician has identified an appropriate patient, they must ensure that the patient has no contraindications to the placement of an intraosseous needle. Next, the provider must select a proper insertion site, which is dependent upon device availability and patient anatomical considerations. Since each clinical practice site may have different devices available, it cannot be overemphasized that it is best practice for the clinician to familiarize themselves with the available supplies *prior* to use in an emergent situation.

Contraindications

Intraosseous access is generally used in emergent conditions, and there are few absolute contraindications. In general, the clinician should avoid an insertion site which has a disruption of the circulatory system feeding the selected long bone. If a disruption exists, the infused medications or intravenous fluids will exit through the defect rather than enter the systemic circulations. Examples include:

- Fractured bone
- Previous failed intraosseous attempt in the same bone
- Distal amputation at the selected site

In a manner similar to intravenous catheters, the clinician should choose an alternate location if there are overlying burns or cellulitis or underlying osteomyelitis. Caution should also be taken in individuals with concomitant conditions associated with increased fragility of their skeletal system, such as osteoporosis or osteogenesis imperfecta [3].

Risks/Benefits

Current cardiac arrest guidelines recommend early serum laboratory studies to steer resuscitative efforts toward the correction of reversible causes, but intraosseous infusion is often the only access reasonably achievable in these critically ill patients. Bone marrow samples from an intraosseous line may be a source of accurate results for levels of sodium, chloride, blood urea nitrogen, creatinine, glucose, and hemoglobin. However, serum potassium results drawn from an intraosseous line are frequently higher than venous or arterial samples, potentially confounding the clinician's assessment of the cause of the patient's critical illness [5]. Additionally, the studies examining intraosseous blood samples were animal studies or were performed on healthy individuals, and their extrapolation to critically ill patients is limited. Finally, point-of-care devices are frequently employed during resuscitations and offer quick bedside results to the clinician. However, these devices are not calibrated to analyze bone marrow samples, and results may not be accurate. In summary, samples from an intraosseous line may be sent for laboratory analysis, but the results should be interpreted with caution.

Clinicians often are hesitant to place an intraosseous needle out of concern for causing pain to the patient. It should be noted that intraosseous access is usually reserved for use in patients that are gravely ill, and the benefits of rapid intravascular access outweigh the risk of inflicting pain. However, patients rate intraosseous needle insertion as less painful than other standard emergent procedures, including placement of urinary catheters, nasogastric tubes, arterial catheters, and central venous catheters (Fig. 14.3). Patients do report high pain scores during rapid or high-volume fluid administration, but this can be mitigated through pretreatment with 2% preservative-free intravenous lidocaine in an initial typical adult dose of 40 milligrams (2 milliliters). In patients that are responsive to pain, consider beginning with a slow intravenous push of this dose, followed by a rapid normal saline 10 milliliters flush over 5 seconds. The rapid flush is necessary to establish a free-flowing outlet for the infusion and is usually reported as the most painful part of the procedure. Following the normal saline flush, an additional 20 milligrams (1 milliliter) of 2% preservative-free intravenous lidocaine is again slowly pushed. Completion of this medication regimen before pressure infusions of large volumes of intravenous fluids significantly reduces reported pain scores [6].

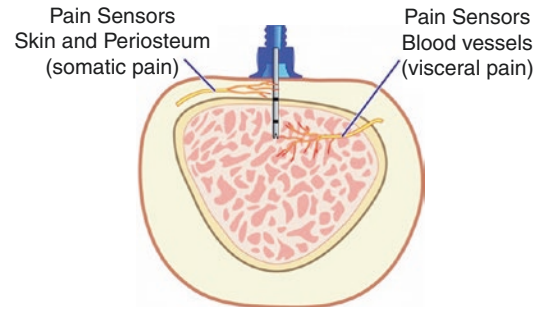

Fig. 14.3 IO pain anatomy

Preparation

- Gather supplies (Fig. 14.4):
  - Chlorhexidine, povidone-iodine, or other antiseptic
  - PPE, gloves, barrier devices
  - Saline flush with extension tubing
  - Padding or commercial stabilization devices

Fig. 14.4 IO supplies

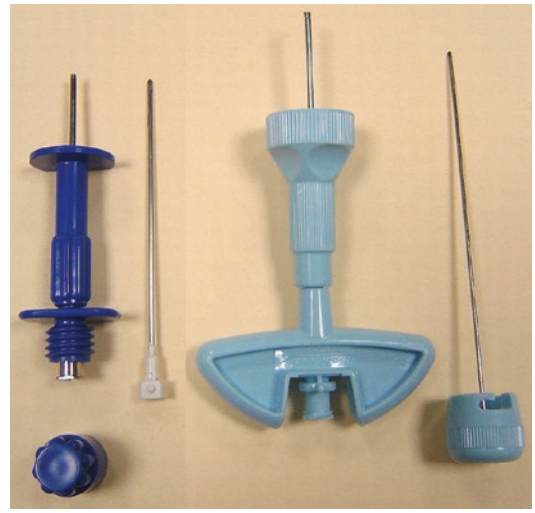

Fig. 14.5 Jamshidi and Illinois IO needles

Fig. 14.6 BIG device

- 2% preservative-free intravenous lidocaine (in responsive patients)
- Intraosseous needle
  - Manual intraosseous needles: Jamshidi and Illinois (Fig. 14.5)
  - Impact devices: Bone Injection Gun (BIG) and FAST1 (Figs. 14.6 and 14.7)
  - Battery driver: EZ-IO (Fig. 14.8)

- Site selection:
  - Proximal tibia (Fig. 14.9)
    - 1–3 cm (2 finger widths) distal to the tibial tuberosity.
    - The proximal tibia offers a wide, flat surface which aids in placement; slight external rotation of the foot eases insertion at a 90-degree angle.
    - Insertion site with the highest first-pass success rates.
    - Appropriate for adult and pediatric patients.

Fig. 14.7 FAST-1

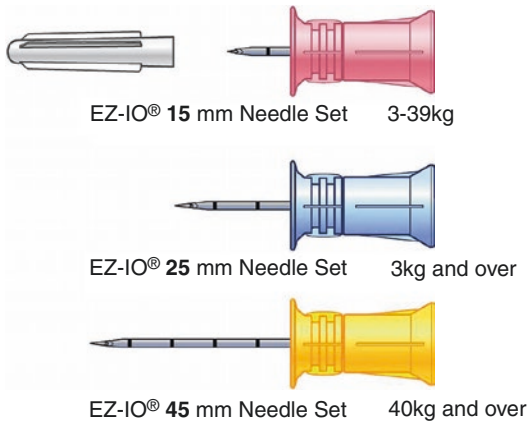

Fig. 14.8 EZ-IO needles

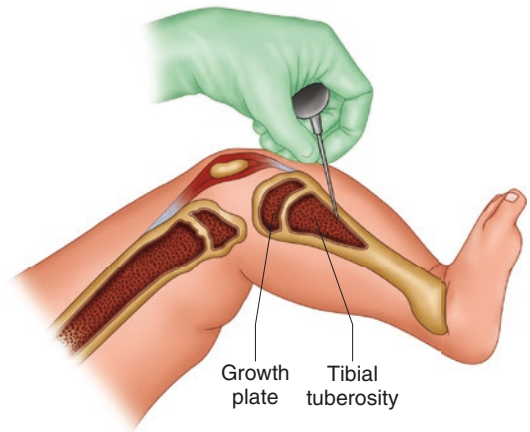

Fig. 14.9 Proximal tibia IO site

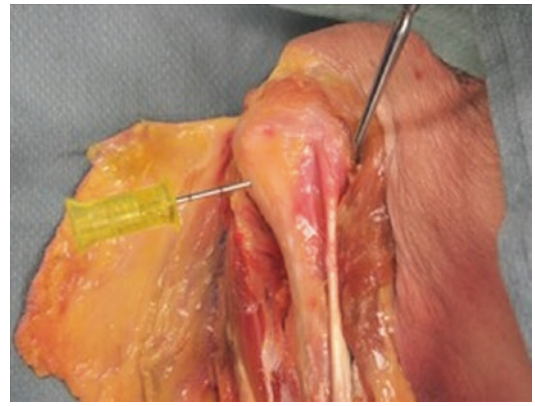

Fig. 14.10 Prox humerus IO cadaver

In responsive patients, high pain scores reported with large volume infusions.

– Proximal humerus (Fig. 14.10)

1 cm superior to the surgical neck of humerus, place arm in an adducted position with internal rotation (hand overlying the umbilicus) and locate the greater tubercle of the proximal humerus by palpating approximately 2 cm below the acromion process or palpating superiorly along the humerus.

Anatomy and overlying soft tissue make landmark identification more difficult than other sites.

Appropriate for adult and skeletally mature pediatric patients.

Rapid infusion rates with studies showing infusions reaching central circulation at speeds similar to central venous catheters.

Lower first-pass success rates when compared to the proximal tibia, also higher rates of needle dislodgement.

Responsive patients report lower pain scores with high-volume infusions when compared to other insertion sites.

– Sternum (Fig. 14.11)

1.5 cm inferior to sternal notch, the body of the manubrium.

Appropriate for adult patients.

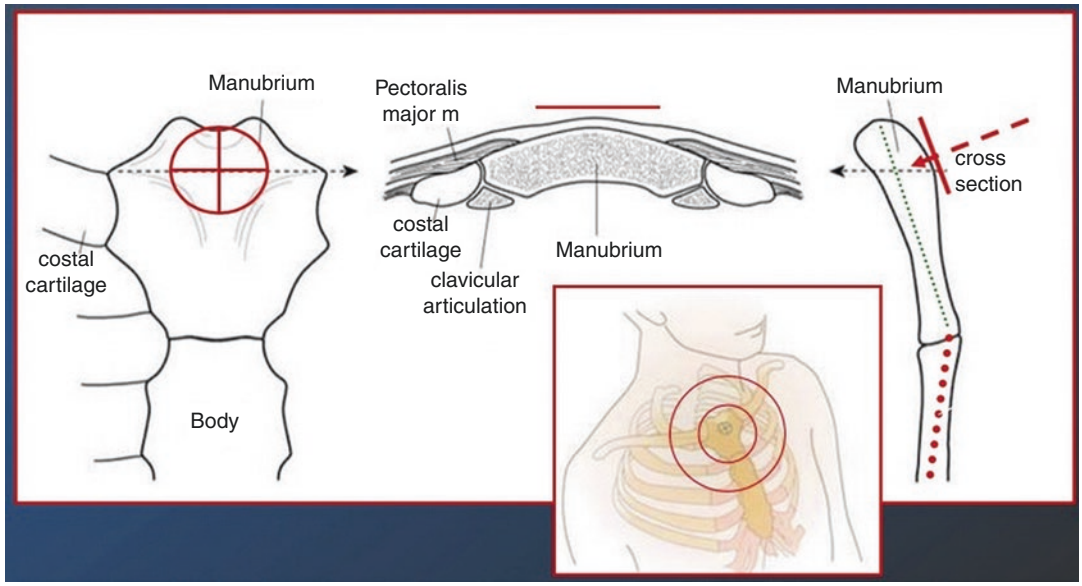

Fig. 14.11 Sternal IO site

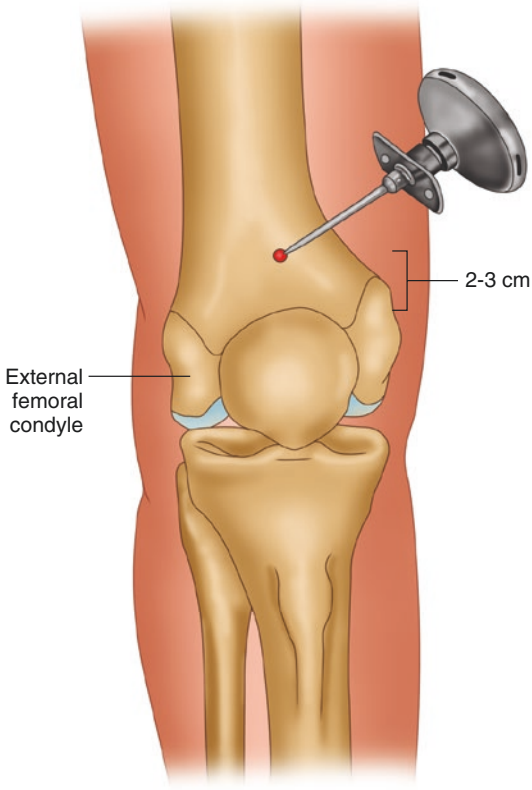

Fig. 14.12 Femur IO site

Only accessible with the FAST-1 intraosseous device and EZ-IO TALON devices.

High flow rates reported; its use is popular in military/tactical applications.

– Distal femur (Fig. 14.12)

1–2 cm proximal to the patella, or midline 2–3 cm proximal to femoral condyles.

Appropriate for pediatric patients (off-label in adults).

Anatomy and overlying soft tissue make landmark identification more difficult than other sites.

– Distal tibia/medial malleolus (Fig. 14.13)

1–2 cm proximal to the medial malleolus

Appropriate for adult and pediatric patients

Less studied than other insertion sites but remains a valid option, presumptively similar to the proximal tibia for subjective pain in responsive patients

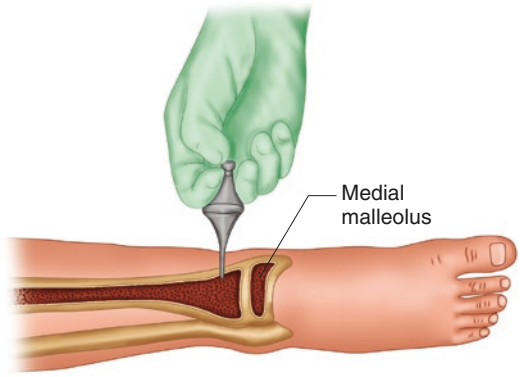

Fig. 14.13 Distal tibia medial malleolus IO site

Procedure

Pre-procedure (for all devices and insertion sites):

- Check for contraindications.
- Gather supplies, in responsive patients, and consider prepping flush with 2% preservative-free intravenous lidocaine.
- Don personal protective equipment.
- Cleanse selected site as per institutional policy.

Manual insertion:

- Stabilize selected site.
- Insert the needle through the skin and soft tissues at a 90-degree angle until needle tip reaches the periosteum (Figs. 14.14 and 14.15).
- While maintaining a 90-degree angle, apply steady pressure and twist or rotate clockwise and counterclockwise until the needle enters the marrow space; this is usually felt as a "pop" or "give" when resistance suddenly decreases.
- Remove the inner stylet and dispose of in a sharps container (Fig. 14.16).
- Attach primed extension tubing.
- Aspirate bone marrow.
- Flush (consider analgesia as described above) and ensure there is no extravasation into adjacent soft tissues.

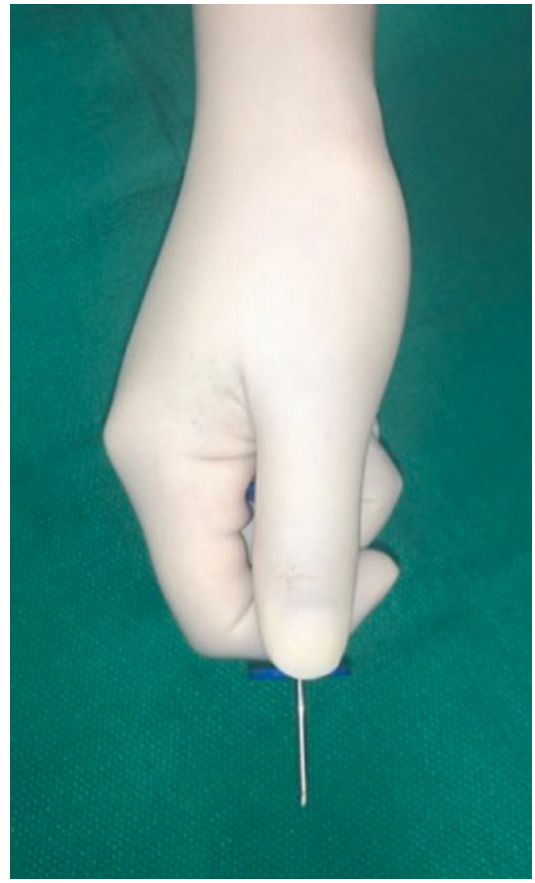

Fig. 14.14 IO correct insertion angle

- Secure with padding.
- When no longer needed, remove with steady firm traction at 90-degree angle and twisting motion (similar to insertion) and dispose of the needle in a sharps container; after removal, apply pressure and dress wound.

EZ-IO:

- Select appropriate length needle (Pink 15 mm, Blue 25 mm, Yellow 45 mm) for patient's weight/overlying depth of soft tissue; attach to the EZ-IO Power Driver (magnetic) (Fig. 14.17).
- Stabilize selected site.
- Remove the needle cover by grasping and briefly pulling the driver trigger.
- Insert the needle through the skin and soft tissues at a 90-degree angle until needle tip

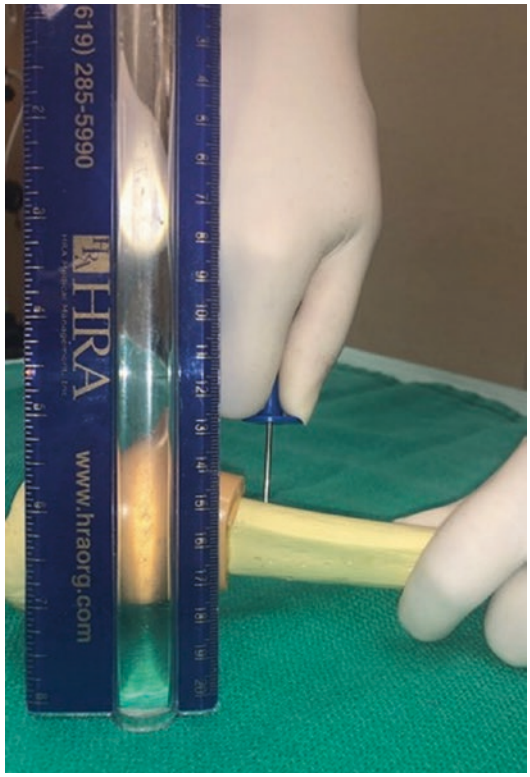

Fig. 14.15 IO correct insertion angle 2

reaches the periosteum; ensure that the 5 mm black mark on the needle is still visible (ensures adequate needle length to reach the bone marrow) (Fig. 14.18a–c).

- While maintaining a 90-degree angle, apply steady pressure and squeeze the driver trigger; when the needle enters the marrow space, the change in resistance is noted by a difference in the pitch of noise from the power driver and a marked decrease in resistance.
- Remove the driver from the needle (pull straight back to disconnect the magnetic coupling), remove the inner stylet, and dispose of the stylet in a sharps container.
- Consider placing the commercially available EZ-Stabilizer dressing.
- Attach primed extension tubing.
- Aspirate bone marrow.
- Flush (consider analgesia as described above) and ensure there is no extravasation into adjacent soft tissues.
- Secure with the available EZ-Stabilizer dressing or padding.
- When no longer needed, remove the extension tubing and attach a Luer lock syringe; remove with steady firm traction at a 90-degree angle and twisting motion; dispose of the needle in a sharps container; after removal, apply pressure and dress wound.

FAST-1 Device (Fig. 14.19):

- Identify the insertion site and apply the included target patch (Fig. 14.20).
- Remove the sharps caps from the device.
- Place the circular bone probe needles in the center of the target zone.
- While maintaining a 90-degree angle, apply steady pressure until a “pop” indicates the central intraosseous needle has entered the bone marrow space.
- Remove the device handle and attach primed extension tubing.
- Aspirate bone marrow.
- Flush (consider analgesia as described above) and ensure there is no extravasation into adjacent soft tissues.
- Attach the included round plastic protector dome (Fig. 14.22).
- When no longer needed, remove the extension tubing, remove the orange safety latch and seat the catheter hub in the square notch (a Luer lock syringe may also be utilized), remove with steady firm traction at a 90-degree angle, and dispose of device in a sharps container; after removal, apply pressure and dress wound.

BIG (Bone Injection Gun) Device (Fig. 14.6):

- Identify the insertion site and place device at a 90-degree angle with the non-dominant hand.
- Squeeze and remove the orange safety latch from the device.
- While maintaining a 90-degree angle by holding firmly with the non-dominant hand, apply steady pressure and press the palm of the

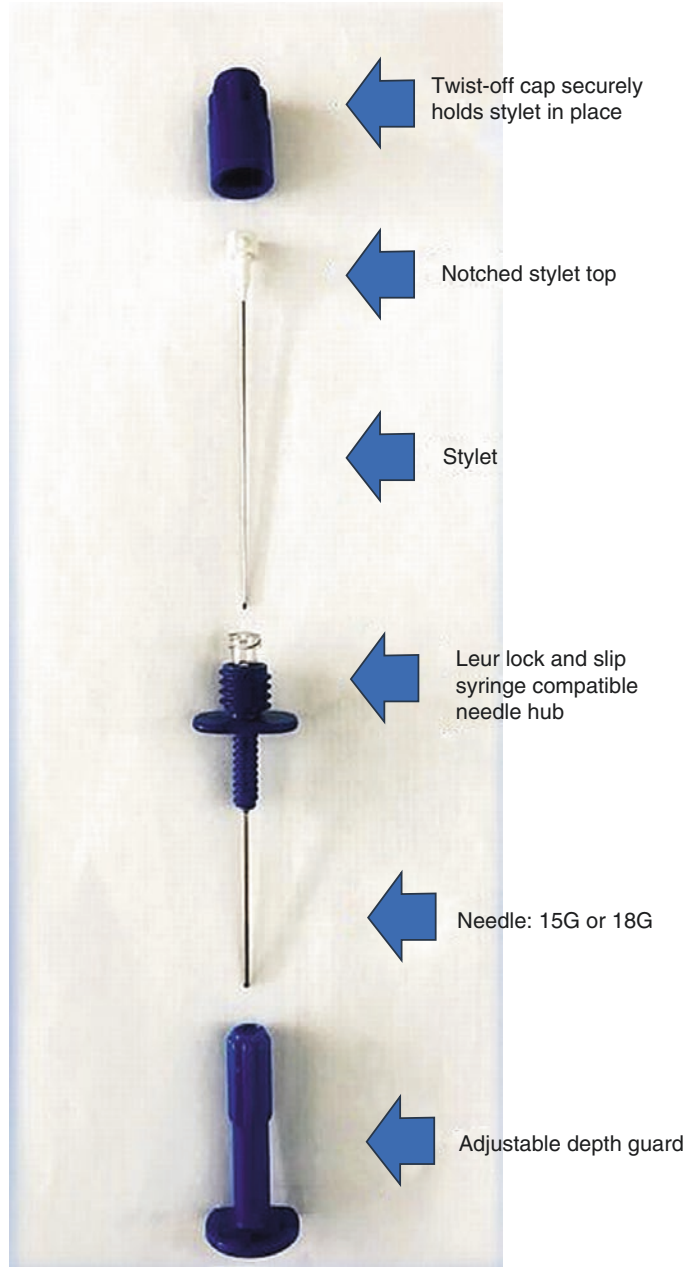

Fig. 14.16 Jamshidi needle detailed

dominant hand on the device until a "pop" is heard which indicates the central intraosseous needle has deployed and entered the bone marrow space.
- Remove the device by pulling upwards.
- Remove the inner stylet and dispose of in a sharps container.
- Secure with the orange safety latch and tape.
- Attach primed extension tubing and aspirate bone marrow.
- Flush (consider analgesia as described above) and ensure there is no extravasation into adjacent soft tissues.
- When no longer needed, remove the protective dome and extension tubing, remove with steady firm traction at a 90-degree angle and

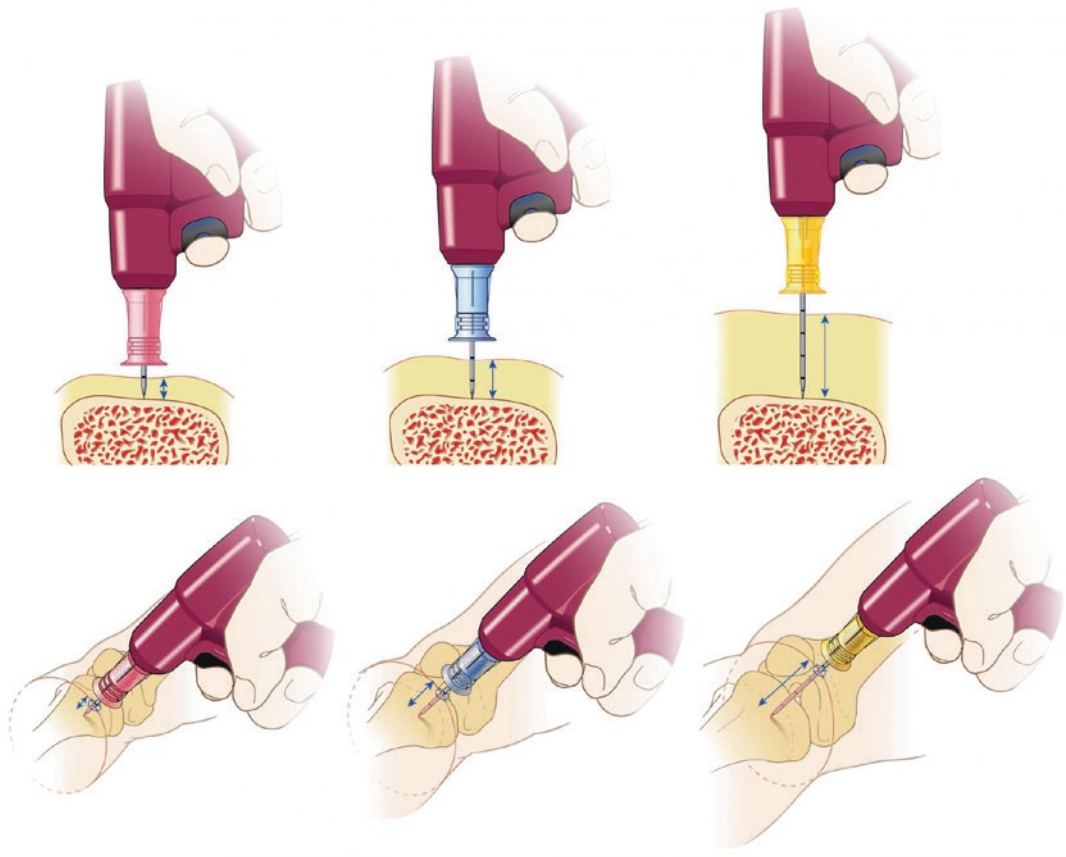

Fig. 14.17 EZ-IO needle depth guide

twisting motion, and dispose of device in a sharps container; after removal, apply pressure and dress wound.

Pre-procedure (for all devices and insertion sites): The clinician should monitor the intraosseous access site for signs of dislodgement and extravasation into the adjacent soft tissues. These complications can be mitigated by protecting the insertion site with commercially available securement devices or padding. The intraosseous needle may be left in place for up to 24 hours, but the clinician should consider that rates of complications and infections increase with prolonged access [4]. Intraosseous access may often serve as a "bridge" until the patient's condition has improved, and traditional methods of intravenous access may be completed in a safe manner. As described in the procedure, the needles are easily removed with steady traction, and the site only requires standard wound care afterward.

Complications

Generally, an intraosseous infusion is considered to be a safe procedure. The most common clinical complications are the inability to adequately place the device in the marrow space and dislodgement of the needle. Osteomyelitis and intraosseous abscess are rarely reported complications [7], and their incidence is significantly reduced through the use of aseptic technique and ensuring the needle is not left in place longer than the recommended 24-hour period [3]. Extravasation of infused fluids, whether from

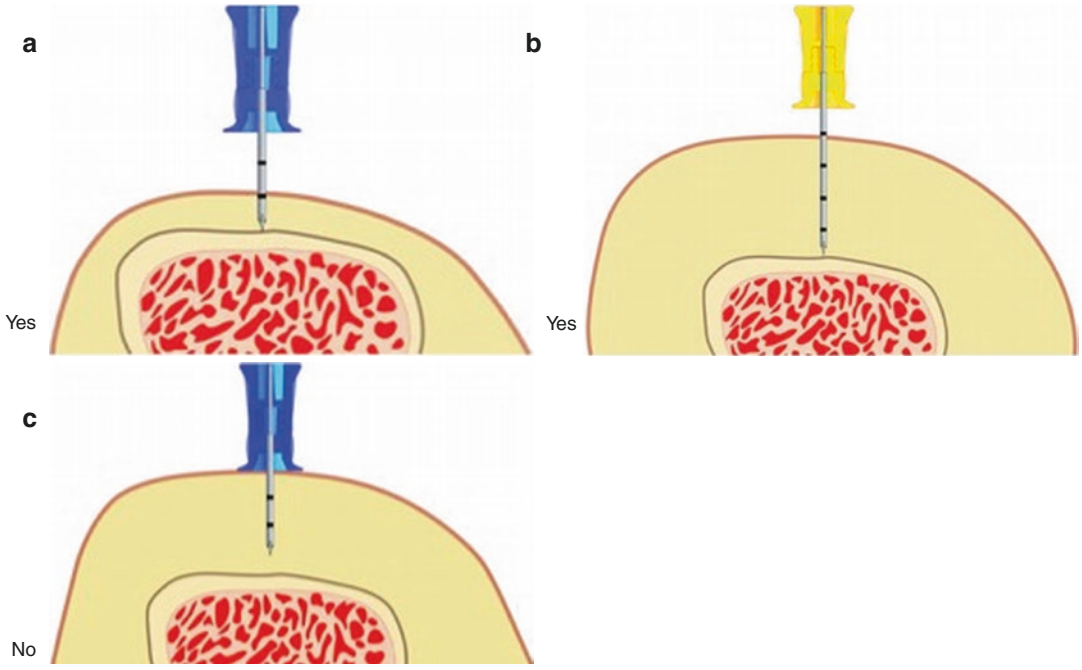

Fig. 14.18 (**a**) Correct depth cutaway. (**b**) Correct depth cutaway 2. (**c**) Incorrect depth cutaway

Fig. 14.19 FAST1 system

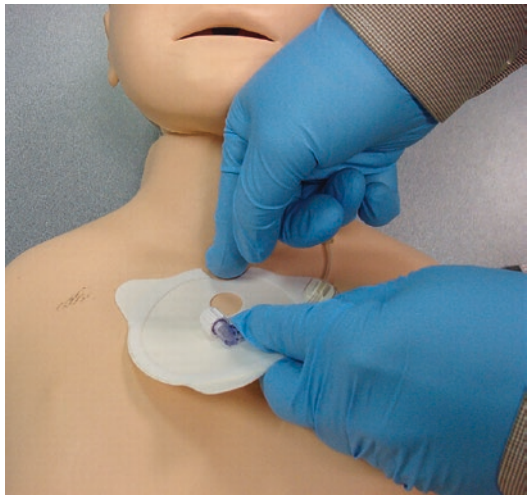

Fig. 14.20 FAST1 patch application

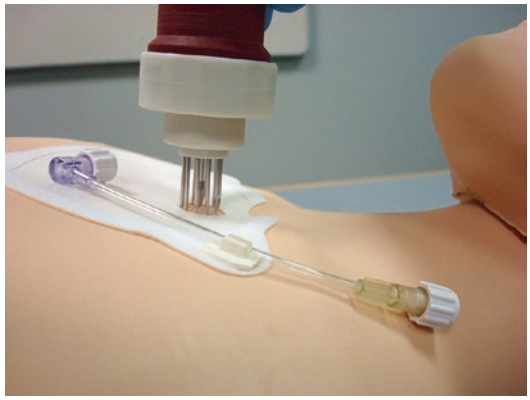

Fig. 14.21 FAST1 sternum alignment

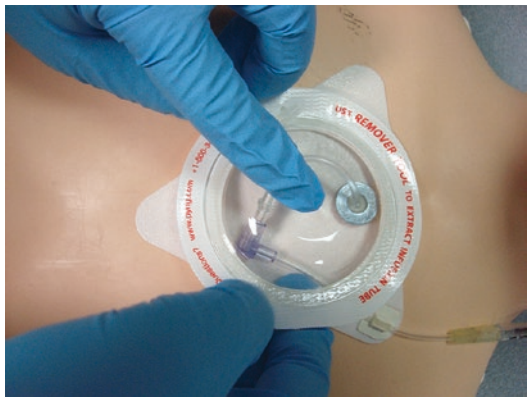

Fig. 14.22 FAST1 protector dome

needle dislodgement or a "through and through" extension of the needle into the subcutaneous tissues on the opposite side of the targeted long bone, can result in a compartment syndrome. Extravasation has been most commonly described in the lower extremities, but there are reports of compartment syndrome occurring with humeral intraosseous insertion [8]. Microscopic fat and bone marrow emboli have been reported, though there has not been a demonstration of clinical significance [9].

Keys to Success, Perils, and Pitfalls

- Intraosseous access is indicated in critically ill patients with actual or predicted difficulty in accessing the peripheral vasculature through traditional methods.
- Clinicians are often reluctant to place an intraosseous needle for fear of causing the patient pain. However, this fear is misplaced as patients report that intraosseous needle placement is less painful than other commonly performed emergent procedures.
- Patients do frequently complain of pain during infusions of large volumes of fluids. Discomfort can be mitigated by preceding infusions with 2% cardiac lidocaine as described above.
- The humeral insertion site is usually associated with faster delivery of medications and fluids to the central circulation. However, this site is also associated with a higher rate of failure and complications. The proximal tibia insertion site is generally easiest to access, and the slower delivery of medications or fluids is of uncertain clinical significance.
- Any medication or fluid that can be given through traditional intravenous access may also be delivered through intraosseous access.

CPT Coding

The appropriate CPT code for intraosseous access and infusion is 36680. As described, the procedure is a relatively rapid means of obtaining

vascular access used primarily in critically ill patients. Subtracting the time needed for intraosseous needle placement, if the clinician has devoted between 30 and 74 minutes of time evaluating or managing a critically ill patient, they should also code for 99291 and for 99292 for additional increments of 30 minutes.

Summary

Intraosseous infusion offers a rapid and reliable method for accessing a patient's circulation. While it may seem like a painful procedure, patients describe it as less painful than many other procedures frequently performed in urgent or emergent situations. Regardless, the clinician has methods to mitigate this pain through the use of intravenous lidocaine. The provider has a variety of insertion sites and devices available to allow for intraosseous access. Institutional policy and purchasing decisions may limit which choices are available, and pre-procedure planning is recommended for familiarization before a patient presents to the clinical practice site. The proximal tibia offers the highest rate of first-pass success but is also associated with higher patient-reported pain scores and lower infusion rates. The proximal humerus offers infusion rates that rival central venous access and lower patient-reported pain scores but is associated with a lower first-pass success rate and higher needle dislodgement rates than the proximal tibia.

Additional Resources

See attached videos (Figs. 14.23, 14.24, 14.25, 14.26, 14.27, 14.28, 14.29, and 14.30) and images (Figs. 14.1, 14.2, 14.3, 14.4, 14.5, 14.6, 14.7, 14.8, 14.9, 14.10, 14.11, 14.12, 14.13, 14.14, 14.15, 14.16, 14.17, 14.18, 14.19, 14.20, 14.21, and 14.22), with special appreciation and recognition for the assistance with images and video from Scotty Bolleter, LP and the staff of the Centre for Emergency Health Sciences.

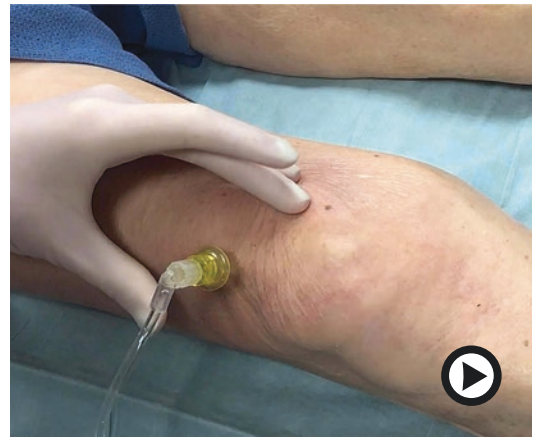

Fig. 14.23 Distal Femur EZ-IO Insertion (off-label). (https://doi.org/10.1007/000-2rg)

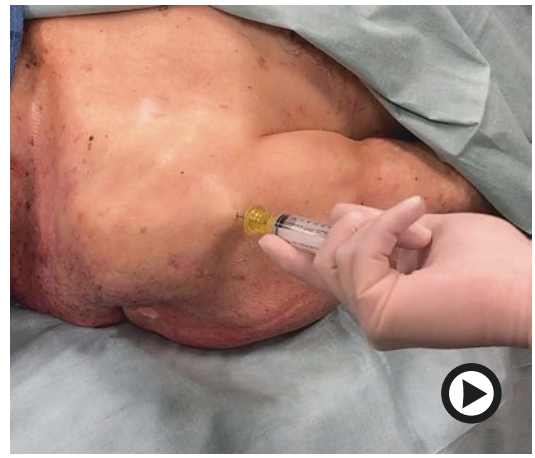

Fig. 14.24 EZ-IO Removal (https://doi.org/10.1007/000-2rd)

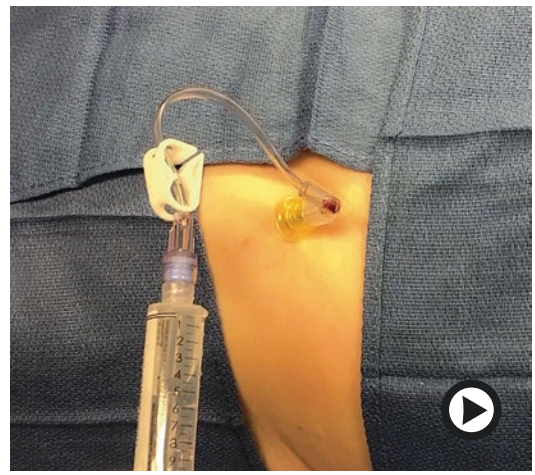

Fig. 14.25 IO Marrow Aspiration (https://doi.org/10.1007/000-2re)

Fig. 14.26 IO Videos (https://doi.org/10.1007/000-2rf)

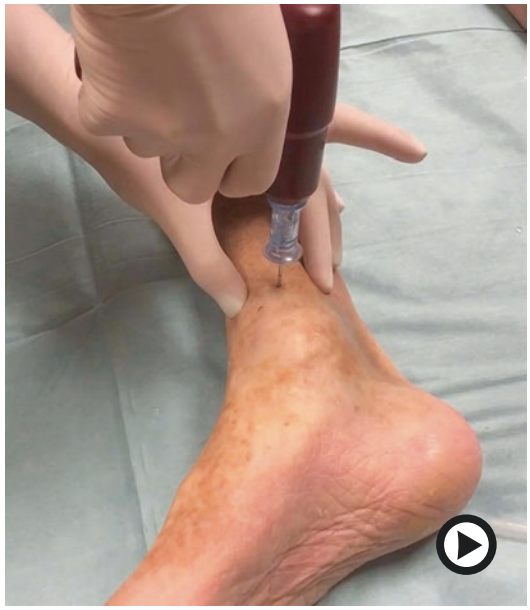

Fig. 14.27 Medial Malleolar EZ-IO (https://doi.org/10.1007/000-2rc)

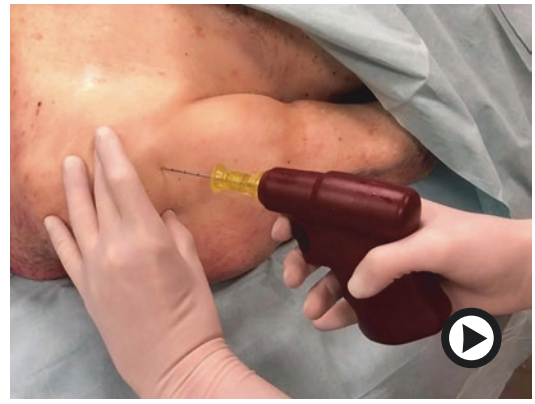

Fig. 14.28 Proximal Humerus EZ-IO Insertion (https://doi.org/10.1007/000-2rh)

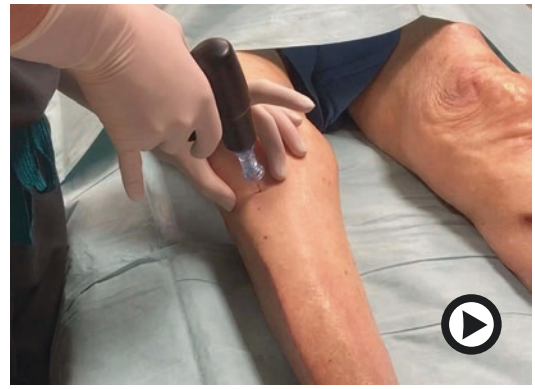

Fig. 14.29 Proximal Tibia Angle Adjustment (https://doi.org/10.1007/000-2rj)

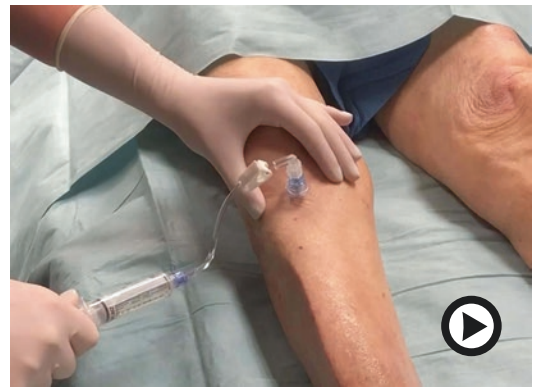

Fig. 14.30 Proximal Tibia EZ-IO Insertion (https://doi.org/10.1007/000-2rk)

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15 Pulmonary Artery Catheter Insertion

Dennis A. Taylor, Robert Shayne Martin, and Rachel Lynne Warner

Introduction

Pulmonary artery catheters (PACs) were introduced in the 1970s as a means to monitor the cardiovascular function of critically ill patients. This balloon-tipped catheter is advanced by blood flow through the right atrium and right ventricle and then terminates with its distal tip in the pulmonary artery. Due to the location of the catheter, this technology offers clinicians real time pressure and volume measurements across the right heart with the added ability to estimate left heart physiology [10].

The use of PACs has been controversial since their inception and continues to be debated among intensivists today. Several randomized controlled trials have concluded that there is no outcome benefit associated with the use of PACs in high-risk surgical patients, congestive heart failure, acute lung injury, and sepsis [3, 6–8]. In the acute myocardial infarction cohort, evidence has shown an increased risk of mortality with the use of PACs [2].

However, in specific patient populations, the application of PACs may prove beneficial. The ATTEND trial suggested that PAC use in patients with acute heart failure was beneficial, especially in the setting of hypotension or the need for inotropic support [9]. Furthermore, the use of PACs represents the standard of care in patients with severe pulmonary hypertension and those undergoing preoperative evaluation for liver transplantation [1, 4].

Regardless of the controversy, PACs are still believed by many to have a role in the care of the critically ill and injured. Practitioners must be fully aware of the indications and the prudent application in selected patient populations. Indeed, practitioners should consider the utility of less invasive monitoring technologies as alternatives where applicable. Additionally, they should be experts in interpretation of the data provided by PACs and be comfortable translating it to guide therapy.

Indications

There is currently no evidence to suggest that the routine use of PACs results in improved patient outcomes [4]. Nevertheless, the effective use of PACs can provide a powerful tool to guide interventions in critically ill patients. In their recent

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review of the use of PACs, Gidwani, Mohanty, and Chatterjee [4] recommended the following list of indications for PA catheterization in the critical care setting:

- Patients undergoing liver transplantation work-up
- Patients with cardiogenic shock receiving supportive therapy
- Patients with discordant right and left ventricular failure
- Patients with severe chronic heart failure requiring inotropic, vasopressor, and vasodilator therapy
- Patients with potentially reversible systolic heart failure
- Patients being evaluated for pulmonary hypertension
- Patients who are being treated for precapillary and mixed types of pulmonary hypertension to assess their response to therapy

The PAC can be used for both diagnostic and therapeutic purposes. Practically, a common reason for the use of a PAC is the need to determine intravascular volume status when less invasive means have proven ineffective. The clinician should evaluate the goal of placement and the inherent risks to assess whether insertion benefits that particular patient and outweighs risk. With the advent of alternative technologies in hemodynamic monitoring and evidence disputing the efficacy of PACs, there has been decreased utilization across the United States [11].

Contraindications

The advanced practice provider should weigh the risks and benefits prior to insertion of the PAC. There are no absolute contraindications for this procedure, but there are several relative ones.

A common relative contraindication is preexisting left bundle branch block (LBBB). An electrocardiogram should be obtained prior to the insertion of the PAC to rule out the presence of LBBB. The risk of insertion for a patient with a LBBB is that injury or disruption of the right bundle could result in complete heart block and asystole. In the event a PAC is absolutely necessary in a patient with a LBBB, the practitioner should anticipate this complication and be prepared for direct cardiac pacing.

The following is a summary of additional relative contraindications for insertion of a PAC:

- Right-sided heart mass (thrombus or tumor)
- Presence of pacer or defibrillator electrodes
- Severe coagulopathy or current systemic anticoagulation therapy
- Tricuspid valve prosthetic or stenosis
- Severe hypothermia

Informed Consent

Prior to beginning the PAC insertion, the practitioner must obtain informed consent from the patient or their designated surrogate decision-maker. In order to properly obtain consent, the risks and benefits of the procedure must be described to the person signing the consent release.

Benefits to be discussed include improved hemodynamic data acquisition derived from the PAC to better guide therapy. The presentation should explain that insertion will allow real-time information to help direct medication and fluid delivery to the patient.

Providers should discuss the indications as well as contraindications and recommendation to proceed with PAC placement. Risks associated with the procedure itself, as well as the use of the catheter after insertion, should also be disclosed.

The most common complication during insertion is the occurrence of cardiac arrhythmias including ectopy and tachyarrhythmias. They are usually short-lived, but occur in 12.5–70% of insertions, with only about 3% require antiarrhythmic therapy [3]. In addition, there is approximately a 0.5–1% risk of pneumothorax and hemothorax during insertion.

Infection is always a risk of insertion of a foreign object into the human body. Infections can occur in the subcutaneous tissue at the insertion site, in the blood stream, or in the heart tissue

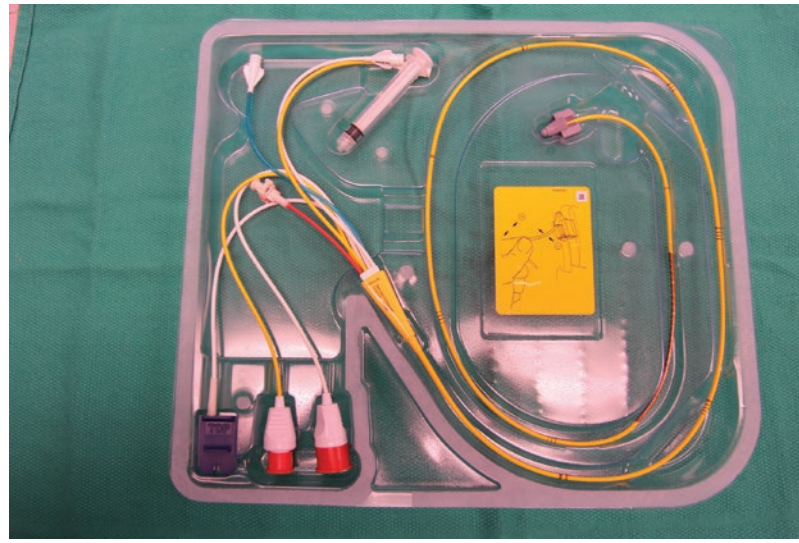

Fig. 15.1 PA Catheter kit

itself. The risk of bacteremia associated with PACs ranges from 1.3% to 2.3%, and endocarditis is described in 2.2%–7.1% of these cases [3]. Patients with prosthetic valves are at higher risk for endocarditis [3].

Pulmonary artery rupture is perhaps the most severe complication associated with PA catheterization, although it is extremely rare with an incidence of 0.03–0.20% [3]. Risk factors for perforation include pulmonary hypertension, hypercoagulopathy, age greater than 60, improper catheter positioning, and improper balloon inflation [3].

As you prepare to complete the consenting process, it is important to acknowledge that there is always an overall risk of death when undergoing invasive procedures. In one study of critically ill patients, 4% died from complications related to the PA catheter with an estimated 20–30% experiencing other major complications related to the catheter [5]. Clinicians should remind themselves that procedure is completely benign.

Preparation

Prior to beginning the procedure, it is important to gather all the necessary equipment as well as to inform the bedside registered nurse who will assist during the procedure with the equipment setup (Figs. 15.1 and 15.2a). Most intensive care units are equipped with PAC kits that contain all the necessary supplies needed for insertion; however, the provider may choose to obtain extra pressure tubing, saline flushes, sterile skin prep, and gauze sponges. The nurse will zero the transducer and enter the patient-specific demographics into the monitor prior to insertion so that the information is calculated correctly for your patient.

Procedure

In order to reduce the risk of bacteremia, this procedure is performed using sterile technique. All persons in the room should be required to wear masks and a surgical cap during the insertion. The provider should wear sterile gloves, gown, mask, and a surgical cap. The patient's insertion site should be prepped with chlorhexidine and draped with full-body drapes.

If an introducer catheter is not yet in place, one must be placed using the Seldinger technique. The most direct insertion site for placement of the PA catheter is either the left subclavian or the right internal jugular vein; however, any insertion site including a femoral approach is appropriate. This introducer catheter is larger in diameter than a triple lumen central venous catheter but is

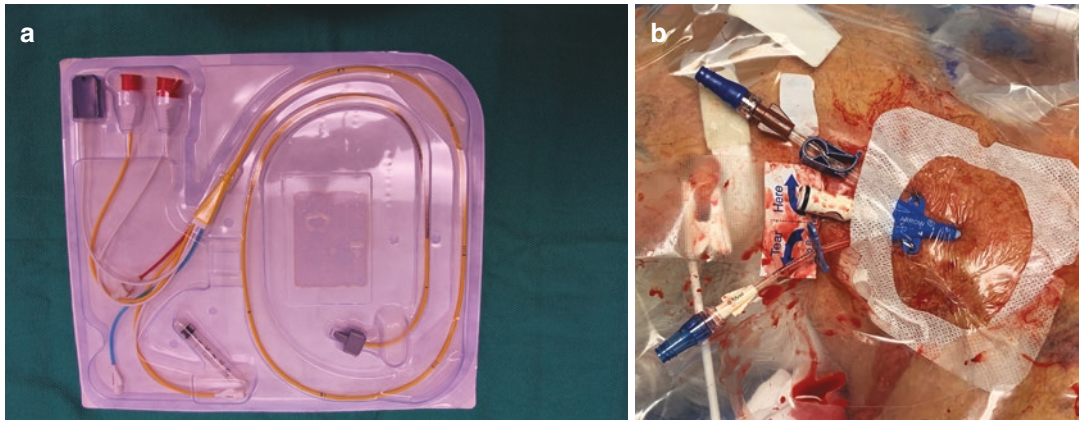

Fig. 15.2 (**a**) PA catheter kit; (**b**) large MAC/cordis central venous catheter in the right IJ

inserted similarly. During insertion, it is imperative that the provider ensure that the introducer catheter is placed in the venous vasculature using one or more confirmatory techniques. Dilation of the arterial system can be catastrophic. Using a jugular or femoral approach will allow for ultrasound confirmation prior to PAC insertion (Figure 15.2b).

Once the patient is prepped and draped and the introducer is in place, the PAC itself must be tested prior to insertion. All the ports should be flushed with sterile saline, and the balloon should be tested for inflation (Figs. 15.3, 15.4, and 15.5). The provider should ensure that the tip is enclosed into the balloon upon inflation and it should not extend past the balloon to prevent damage to the tissue upon insertion. The catheter should also have the protector sterile sheath covering it so that manipulations can occur via a sterile field after insertion is complete.

After the catheter is connected to the pressure transducer and the monitor, the provider should wave the tip of the catheter to make sure it is properly connected by confirming a wave formation on the monitor. Finally, the ACP should orient the catheter so that its natural curvature is in alignment with the vasculature system depending on the insertion site.

Once the tip has been inspected and monitor connection confirmed, the catheter is inserted into the introducer approximately 20 cm until the tip is advanced past the end of the introducer. The catheter has measurement markings along its side to help the provider determine the length inserted into the patient (Figs. 15.6, 15.7, and 15.8). One should confirm placement in the central circulation via the waveform on the monitor (Fig. 15.9

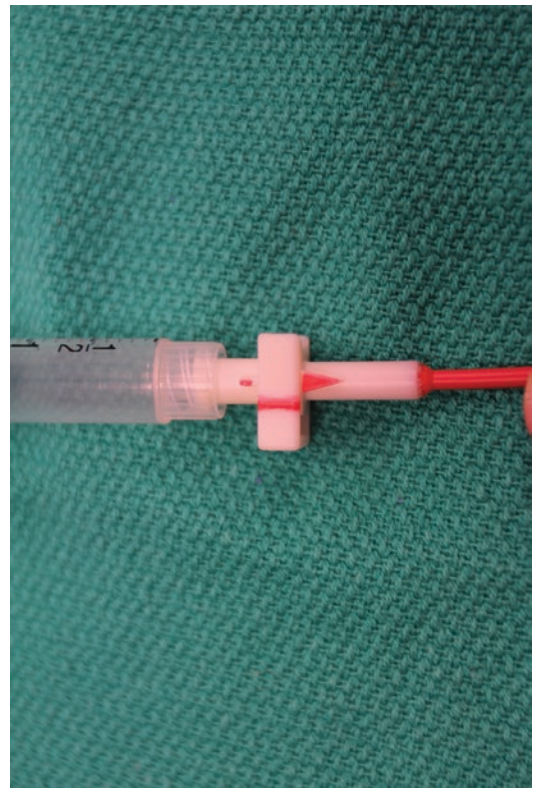

Fig. 15.3 Balloon port lock

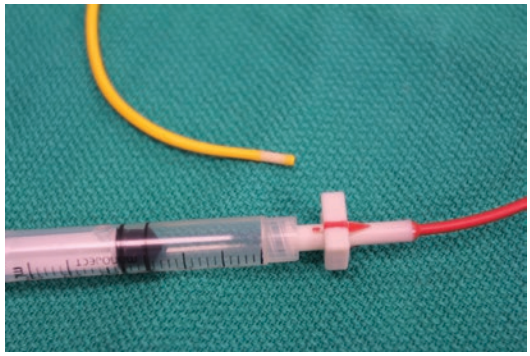

Fig. 15.4 Balloon down

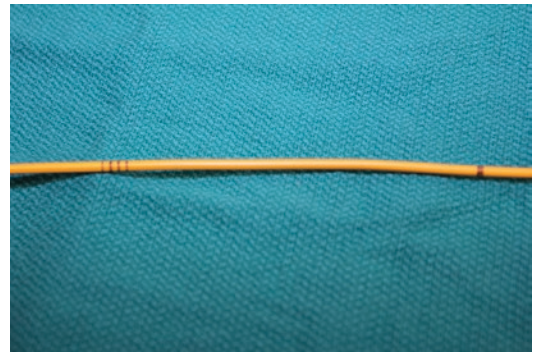

Fig. 15.7 40 and 50 cm marks

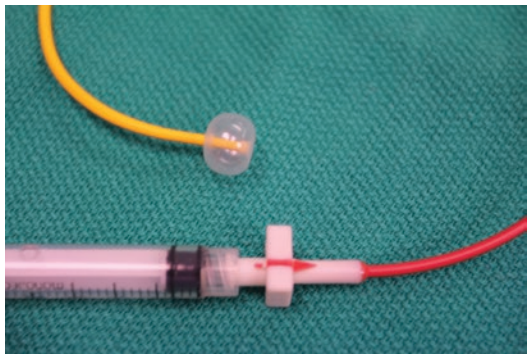

Fig. 15.5 Balloon up

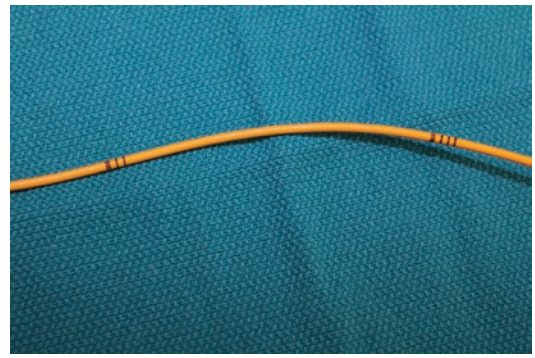

Fig. 15.8 70 and 80cm marks

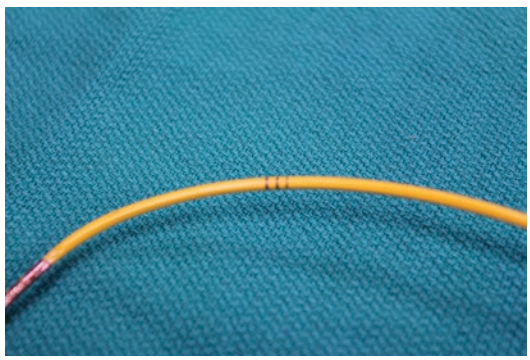

Fig. 15.6 30 cm length markings

and 15.10a,b). During insertion the provider should always reference the monitor to verify location within the heart chambers.

Upon confirmation that the tip is in the central circulation, the balloon should be slowly inflated. The registered nurse assisting with the procedure should state when they inflate or deflate the balloon. Once inflated, the syringe should be locked to the catheter. The provider then advances the catheter quickly into the right ventricle which should occur around 30 cm. This position is then confirmed by the right ventricle waveform on the monitor (Figs. 15.9 and 15.10a,c).

The provider continues to advance the catheter through the pulmonary valve which will be identified by a pulmonary artery waveform (Figs. 15.9 and 15.10a,d), a dicrotic notch, and an increase in diastolic pressure. The ACP will recognize the maintenance of the systolic pressure with an associated increase in the diastolic pressure as the tip of the PAC passes through the pulmonary valve. This typically will occur at 40 cm, and the rate of advancement of the catheter should then be slowed. As the balloon continues to be advanced further into the pulmonary artery, it will become wedged, and the tracing will flatten usually at approximately 50–60 cm.

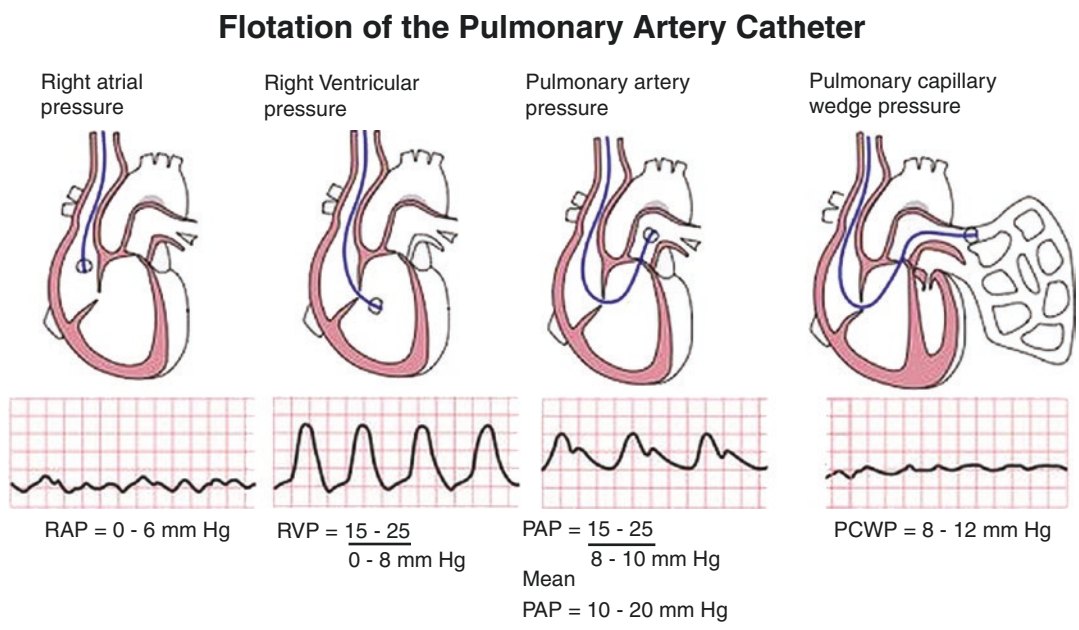

Fig. 15.9 PA catheter waveforms

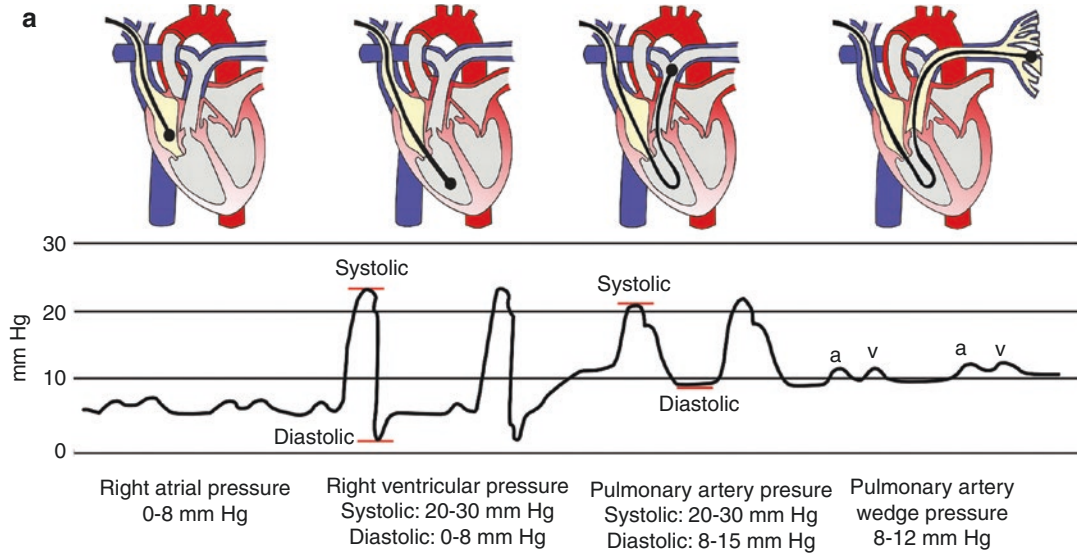

Fig. 15.10 (**a**) PA catheter waveforms; (**b**) PA catheter waveform, SVC/right atrium; (**c**) PA catheter waveform, right ventricle; (**d**) PA catheter waveform, pulmonary artery; (**e**) PA catheter waveform, wedge

Fig. 15.10 (continued)

The balloon should then be deflated and reinflated gently. If there is resistance felt as it is reinflated or the waveform shows signs of overwedging, balloon insertion should be stopped immediately. If the balloon is unable to be fully inflated, this could be a sign that the catheter has passed too far distally and should be deflated and pulled back about a centimeter. The reinflation process should be repeated until the pulmonary artery waveform is lost just as the balloon is fully inflated (Figure 15.10e).

Once the provider feels that the catheter is in proper position and has obtained an appropriate wedge pressure and tracing, the balloon should be deflated and the catheter secured at the length it was obtained via the locking mechanism on the device. This measurement should be recorded in the medical record for reference. A chest x-ray should be ordered to confirm proper placement and rule out complications.

Complications

During insertion, it is possible the balloon will not float easily between the chambers of the heart. When advancing the catheter and a length of 45–50 cm is reached without identifying the pulmonary artery tracing, it is likely that the catheter has become curled into the right ventricle. At

Table 15.1 Hemodynamic profiles

Hemodynamic state	CVP	PAOP	CO	CI	SVR
Normal	2–6 mmHg	8–12 mmHg	4–8 L/min	2.5–4.0 L/min/M^2	900–1300 dynes/sec/cm^{-5}
Cardiogenic shock	↑	↑	↓	↓	↑
Hypovolemic shock	↓	↓	↓	↓	↑
Sepsis	↕	↔	↑	↑	↓
Pulmonary arterial hypertension	↑	↔	↔	↔	↑

this point, the provider would need to deflate the balloon and pull back until the right atrial waveform can be visualized.

The provider should never withdraw the catheter without confirming that the balloon is deflated. The catheter should also never be advanced without the balloon being inflated. Doing either of these maneuvers can lead to perforation or damage to the heart valves or vasculature which is many times fatal.

If an arrhythmia occurs while placing the PAC, the vast majority will be self-limited and not require antiarrhythmic therapy. The PAC balloon should be deflated and the catheter slowly withdrawn until the arrhythmia resolves. Additional attempts at placement can be continued although repeated episodes of ventricular ectopy can limit the ability to successfully place the PAC.

Finally, the clinician should be cautious when obtaining the wedge pressure to ensure that the catheter has not migrated distally. As the catheter warms with the patient's body temperature, it can expand and move. When obtaining a wedge pressure, the balloon should always be inflated slowly so that if early wedging occurs, overinflation can be avoided. Monitoring of placement by the measurement on the catheter is crucial as well as monitoring of placement via chest x-rays.

Pearls

There are several hemodynamic data directly measured by the PAC including central venous pressure (CVP), pulmonary capillary wedge pressure (PCWP), mean pulmonary artery pressure (PAP), and mixed venous oxygenation saturation (SVO_2). When using a volumetric PAC, additional directly measured data include cardiac index (CI) and right ventricular ejection fraction (RVEF). Other measurements are derived from these data including stroke volume index (SVI), systemic vascular resistance (SVR), pulmonary vascular resistance (PVR), end-diastolic volume index (EDVI), and end-systolic volume index (ESVI).

The clinician is able to utilize this information to help direct therapy to support the cardiovascular system. Trends of these calculations can be helpful in goal-directed therapy and in diagnostic evaluation (Table 15.1).

Conclusion

While the utilization of the pulmonary artery catheter in the intensive care unit is on the decline, there are specific populations of patients in which it is beneficial in guiding care. The advanced clinical practitioner working as an intensivist must maintain the skills of insertion and interpretation of the PAC when the need arises.

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Tourniquet Application and Topical Hemostatics

16

Sarah A. Mulkey, Jessica Surane, and Samuel Wade Ross

Tourniquets

Introduction

The use of tourniquets for extremity hemorrhage dates back to at least 1674, when they were first described as being used on the battlefield [1]. Since the beginning, however, tourniquet application has remained controversial [1, 2]. Most of the controversy surrounding tourniquet use is centered on the fact that improper application of a tourniquet can result in severe injury to the patient [1]. When used properly, however, tourniquets can often be a life-saving measure [3]. Two commonly used, commercially available tourniquets are the CAT and SOFT-T Wide [4].

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Indications

First, any external hemorrhage should first be addressed with direct pressure, elevation, and direct arterial compression. Indications for application of a tourniquet can vary depending on the clinical environment. In the hospital setting, a tourniquet is indicated if the patient presents with life-threatening extremity hemorrhage refractory to direct pressure and proximal artery compression [2, 5, 6]. More commonly a patient will present from the pre-hospital setting with a tourniquet in place and you will need to manage them in the Emergency Department.

Contraindications

There are no absolute contraindications to application of a tourniquet on an extremity when the patient is experiencing life-threatening bleeding. The relative contraindications to applying a tourniquet are only applicable in situations where the tourniquet is applied electively to impede blood loss, namely, in vascular and orthopedic operative settings [5].

Risks/Benefits

There are several risks associated with the application of a tourniquet. These include nerve injury,

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tissue ischemia, compartment syndrome, rhabdomyolysis, and thrombosis [5]. Several studies have found the incidence of these complications to be low and far outweighed by the life-saving survival benefit of hemostasis [1, 3, 6].

Preparation

Preparation for tourniquet application is especially important for providers who work in the setting of trauma or postoperative surgical care. To ensure timely application of the tourniquet, it should be stored in the folded manner. To store it appropriately, ensure the buckle is tight and there is no slack between the windlass and the loop. Pull the loop away from the base of the tourniquet such that the tail and loop are approximately the same length. Then, fold the loop back on itself. By folding the tourniquet in this way, it can be opened with one simple pull and, thus, applied to extremity rapidly.

If available, it is also beneficial to have a Doppler at bedside to aid in evaluating distal arterial blood flow and a pair of trauma sheers to quickly cut off items of clothing overlying the extremity wound.

Procedure

In a patient with life-threatening extremity hemorrhage, the objective is to apply the tourniquet early and rapidly to prevent further blood loss. The standard for tourniquet application in a trauma or emergency situation should be less than 15 seconds. To accomplish this, the following steps should be followed with close detail to ensure prompt hemostasis (see Fig. 16.1 for full details).

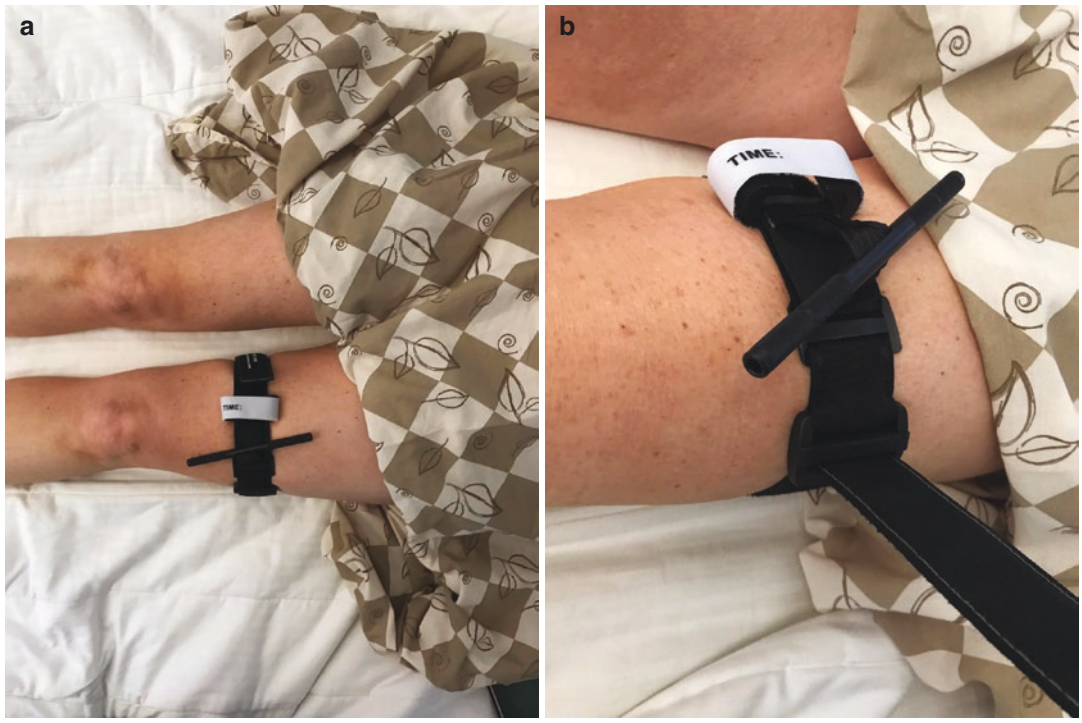

Fig. 16.1 (**a**) Placing the tourniquet above the injury not on a joint, (**b**) tightening the strap toward the person applying it, (**c**) tightening the windlass before securing it in place

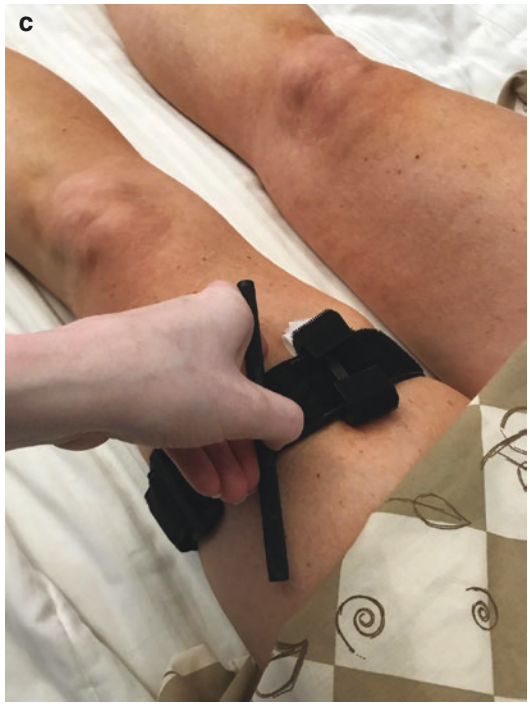

Fig. 16.1 (continued)

Begin by pulling open the tourniquet from its properly stored folded position. This should be one swift movement to open the loop. The tourniquet should be placed 2–3 inches proximal to the bleeding site on the extremity and not over a joint (Figure 16.1a). The base of the tourniquet should be oriented such that the tail end is able to be pulled toward the person applying the tourniquet rather than toward the patient (Figure 16.1b). This orientation permits the applicator to pull the tail against tension to synch the loop down around the patient's extremity. The loop should be synched until there is no slack remaining. Some tourniquets have a rubberized backing on the base that prevents the device from rotating around the patient's arm or leg during application.

Once the tourniquet has been synched to the extremity, the windlass should be turned in a clockwise motion similar to turning a dial (Figure 16.1c). Depending on the location of the tourniquet and the body habitus of the patient, the windlass may be rotated one or several times until the bleeding stops and you can no longer palpate a distal pulse. If the patient is conscious, this will be painful. The windlass should be placed into the notch on the tourniquet sometimes referred to as the anchor. The anchor prevents the windlass from unraveling. Some tourniquets have a tab that can be pulled over the anchor to hold it in place. Frequently the tab will have a spot to write in permanent ink the time of application. If not, the time of application can be written in permanent ink directly onto the tourniquet itself or onto the patient's extremity. Several videos online demonstrate this technique [7, 8]. If bleeding still occurs, apply a second tourniquet. Do not remove the tourniquet already in place. Tighten both until no arterial bleeding is present and no distal arterial pulse is felt.

Procedural Complications

The most critical procedural complication associated with tourniquet application is the creation of a venous tourniquet. When the tourniquet is inadequately synched such that a small amount of arterial flow is still present, blood is able to slowly flow into the extremity [9]. The venous circulation, however, is occluded and blood cannot return. This creates a venous pooling effect and inadvertently increases blood loss [9]. If available, a Doppler can be used to ensure adequate occlusion of arterial flow. If not, it is necessary to repeatedly check a distal pulse.

Keys to Success, Perils, and Pitfalls

There are several key points to application of a tourniquet that can help avoid pitfalls [4]. Some of these include:

- Once a tourniquet has been applied, do not take it down until a plan is established to definitively stop the bleeding.
- If the bleeding does not stop and the windlass is turned as tight as possible, apply a second tourniquet proximal to the first.
- Never apply the tourniquet on or around a patient's joint. The tourniquet should be applied at least 3 inches above the nearest joint when possible.

- A rule of thumb, apply the tourniquet roughly a palms length proximal to the bleeding wound.
- Some tourniquets have a buckle that clips and unclips to facilitate easier placement on the extremity. This can dramatically reduce the amount of time it takes to place a tourniquet, especially on obese patient with a bleeding lower extremity.
- When a commercial tourniquet is not available, a makeshift tourniquet (belt, towel, shirt, blood pressure cuff), while not ideal, is acceptable to prevent exsanguination. Makeshift tourniquets have a much higher incidence of causing complications. Do not stop with the makeshift tourniquet. Quickly identify another method to establish hemostasis and/or a commercial tourniquet.
- When a selective choice is available, chose a wider tourniquet option. Some older tourniquets resemble a band or string with an anchoring device attached. These devices can cut into the skin and cause tissue ischemia.

CPT Coding

There is no specific procedural CPT code.

Summary

Tourniquet application can be a life-saving measure in a patient with severe extremity bleeding. The tourniquet should be appropriately stored in an easily accessible area. Be familiar with each step of the application process as well as the specific institutional tourniquet available for use.

Additional Resources

The Hartford Consensus: How to Use a Tourniquet, Available at: https://www.youtube.com/watch?v=y81aJ81ln5Q

Stop The Bleed: Tourniquet Application, Available at: https://www.youtube.com/watch?v=wWVne7cUrm8&t

Topical Hemostatics

Introduction

Despite advances to modern medicine, hemorrhagic shock remains one of the most prevalent causes of mortality in trauma [10]. Similarly a critical aspect of surgical procedures is controlling intraoperative bleeding. The goal is to utilize appropriate surgical technique and adjunct materials to limit blood loss. With uncontrolled bleeding in surgery or trauma, there are multiple topical agents and modalities that can be used to aid in achieving hemostasis should bleeding occur. These agents are used as adjunct therapy in addition to traditional surgical methods including suture ligation, staples, electrocautery, and energy-based devices. When used appropriately, they can play a vital role in abating hemorrhage [11]. It should be noted that these therapies alone will not correct coagulopathy associated with surgical bleeding, and correction of coagulopathy with balanced damage control resuscitation and transfusion should be utilized.

Topical hemostatic agents can be traced back to 1909 when topical fibrin use was noted to contribute to hemostasis by Bergel. In 1938, purified thrombin became available secondary to technical advancements, and use in the surgical field became more prevalent. In 1960, human clotting factors were able to be isolated from human plasma, and cryoprecipitate was developed. In the 1990s, use of coagulation products became available in the United States. As with all advancements, early agents had many complications; however, over the last several decades, technology has allowed the formation of many different types of agents including powers, gauze, and glues that have aided in more effective control of bleeding [12, 13].

Indications

The indications for hemostatic agents are for uncontrolled surgical-trauma bleeding. With traumatic injuries, these agents can be useful where traditional methods of manual compres-

sion are not enough or there is a large surface area of raw oozing. Additionally, delays in transportation to advanced care centers may prolong the time to complete hemostasis so adjuvant therapies may be useful to improve outcomes. With surgical bleeding, either expected or unplanned, rapid control of bleeding is essential to patient outcomes. In these instances, traditional methods such as suture ligature or electrocautery may not be ideal given the organ system that is bleeding. This is when hemostatic agents may help play a role in minimizing blood loss [14]. In general, topical agents can be used on external and internal bleeding. Different agents are more appropriate given the clinical situation. Wraps or gauze are more applicable for field hemostasis and transport where other more focused modalities may be more appropriate intraoperatively [12, 15, 16]. While some organs can be resected with impunity in emergent laparotomies, topical hemostatic assistance with uncontrolled bleeding from vital organs that must be preserved can be used to control bleeding that would have otherwise been impossible without damage of the organ.

Contraindications

Topical agents are contraindicated for use intravascularly due for increased risk of clotting and thrombosis of the vessels. Additionally, it is not recommended to be used in sites of wound closure as this may slow healing. [12, 17, 18]

Risks/Benefits

Risks of using hemostatic agents include infection, uncontrolled bleeding, risk of thrombosis, allergic reactions, and reduced healing. Additionally, there are increased risks associated with specific patients who may be on anticoagulant or antiplatelet medications. Patients with preexisting medical conditions including diabetes, hypertension, renal disease, or intrinsic bleeding disorders may propose increased risk of complications with bleeding. [15, 19, 20] While these risks are theoretical, in practice topical hemostatics are used in almost all surgical patients when required. Products with active thrombin cannot be used with the use of cardiopulmonary bypass, extracorporeal membrane oxygenation, or in use with cell saver.

However, despite the risks, these agents may be the difference in preventing significant blood loss, morbidity, or even death. Hemorrhagic shock and uncontrolled bleeding can lead to worsening coagulopathy, hypothermia, and end-organ damage. Rapid correction of ongoing blood loss helps prevent long-term complications.

Typically use of these agents does not require consent given the emergent nature of the bleeding. They should be included globally in the risk of elective surgery as risk of bleeding is a common surgical complication. Bleeding risk should always be reviewed prior to surgical procedures. If appropriate, outline specific devices commonly used such as electrocautery and note that other sponges/mesh may be used to aid in hemostasis.

Preparation

Preparing for anticipated bleeding in specific procedures or instances will allow you to have the necessary resources at hand. In routine surgical procedures, agents that are designed to be used in that specific surgical location should be available. In traumatic instances, a wide variety of materials should readily be available. Depending on hospital type, however, resources may be limited, and providers should be aware of their options and indications for use. If preparing for an elective procedure, you should review the patient's medical conditions and medications and discontinue antiplatelet and anticoagulant medications as appropriate.

Procedure

Topical hemostatic agents function in several ways. First, they form a matrix that promotes platelet aggregation and subsequent propagation of the coagulation cascade [18]**.** This promotes aggregation of platelets, formation of a platelet-

fibrin clot, and ultimately thrombus formation locally. Topic agents consist of active agents and passive agents. Active agents work via activation of topical thrombin to active fibrinogen to fibrin and form the clot; this works in conjunction with platelet activation and aggregation to create stable clot formation [12]. Alternatively, passive agents work in the process of matrix formation or work via mechanical pressure. Examples of passive agents include gelatin, collagen, cellulose, and polysaccharides and often work via application onto a sponge which allows for local pressure by manual compression to aid in hemostasis. These mechanisms rely on inherent fibrin and platelet production by the body, and if that process is impaired or depleted, then they will not aid in hemostasis [17].

Hemostatic agents come in many different varieties including gauze, foams, sheets, powders, and glues. Many passive agents come imbedded in gauze, as sheets, and powders, while most active agents are in glues and foams. The type of product can be tailored to the area, tissue type, and amount of bleeding in every situation. Direct pressure with a moist sterile gauze is usually recommended to allow the hemostatic time to help clot propagate. Active agents usually have higher equipment costs and should be used sparingly for mild to moderate bleeding. With larger-volume blood loss, gauzes and pads may be more beneficial as they can provide a larger surface area and work together with compression to stop bleeding [21].

Gelfoam was released in the 1940s and consisted of a gelatin matrix [22]**.** A later released Surgifoam has similar properties [23]. They are water-insoluble absorbable sponge made of porcine gelatin. They can be used as a dry sponge, can be saturated with sodium chloride solution, or can be combined with topical thrombin (Fig. 16.2). The mechanism of action is focused on development of platelet plug formation and when used with thrombin speeds fibrin clot formation**.** Additionally, it has been speculated that mechanical pressure plays a large role on its activation. This material will typically be absorbed within 4–6 weeks, and so this can be left in the body upon placement. It should be noted, however, that excess Surgifoam should be removed once hemostasis is achieved to promote proper healing. Despite being an early hemostatic agent still of great use today, one downfall of gelatin-based agents is their reported higher incidences of infection and abscess formation [23]**.**

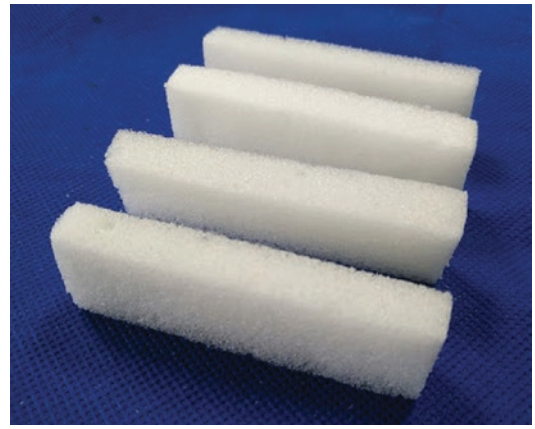

Fig. 16.2 SurgiFoam® gelatin topical hemostatic. (Courtesy of Ethicon Inc.)

Three commonly used agents in orthopedic, cardiovascular (sternotomy), and neurosurgery procedures are bone wax, ostene, and bone putty which work primarily in a mechanical manner to tamponade bleeding. Bone wax is composed of isopropyl palmate, beeswax, and wax-softening agents and works to physically tamponade the bleeding on the surface of the bone. It can also be used to plug holes in the bone where bleeding is coming from the exposed marrow. A very thin amount should be applied [24]. Ostene is composed of a water-soluble polymer which functions in a similar method to bone wax via tamponade; however, it reabsorbs in the body within 48 hours. Finally, bone putty is a resorbable putty that is produced as strips that can be molded into place. It also resorbs in the body over time [12].

Surgicel was released in the 1960s and is an oxidized regenerated cellulose, a passive hemostatic**.** This is an absorbable mesh material which is easily pliable and fits easily into many different spaces and tissue types (Fig. 16.3) [23, 25]. Because of this, it can be manipulated through surgical trocars laparoscopically to aid in hemo-

stasis during minimally invasive procedures. As minimally invasive surgeries become more prevalent, having access to malleable products such as this for hemostasis is becoming of more importance**.** This mesh material is also absorbable and typically gets reabsorbed within 14 days. Other formulations also exist such as Snow, Fibrillar, and Nu-Knit [25]. Snow and Fibrillar come in sheets and are able to be pulled off and manipulated for open surgery to more easily wrap around vessels or on rough edges. Nu-Knit is a thicker mesh like version of Surgicel which can be used to wrap injured solid organs to help provide mechanical compression as well as hemostasis. There is also a powder form of Surgicel which can be sprinkled on raw surface areas for control of capillary, venous, and small arterial hemorrhage. Regardless of the formulation used, one of the benefits of its use is its bactericidal activity which may aid in infection prevention [18]. Other powdered passive agents include Arista, which is water-insoluble, hydrophilic, microporous polysaccharide particles prepared from purified plant starch and is commonly used on raw surface areas. Typical uses are for bleeding around tracheostomy sites, for bleeding at ostomies, and intraoperatively for open and laparoscopic surgery. The original formulation of Surgicel is relatively low cost and is usually available on a variety of wards and operating rooms.

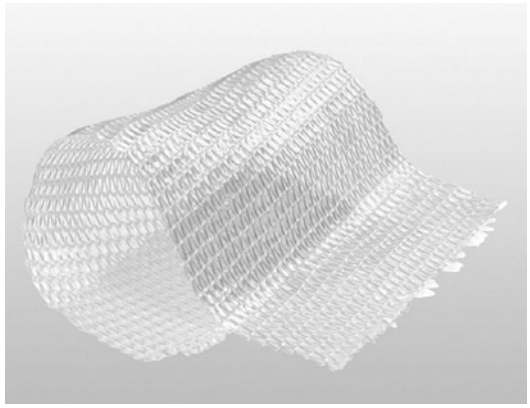

Fig. 16.3 Surgicel® topical hemostatic sheet. (Courtesy of Ethicon Inc.)

Active agents are typically used when there is higher-volume bleeding or from more at-risk areas. Floseal and Surgiflo are two similar products that come in a flowable foam form that can be injected onto the surface of tissue or into cracks in solid organs (Fig. 16.4), specifically the liver, kidney, and spleen. There is thrombin imbedded in the foam gelatin matrix which actively promotes coagulation [13, 19]. More effective but more costly than this are fibrin-thrombin glues that form fibrin clot when the solutions are mixed on spray onto the tissue (Fig. 16.5). Evicel and Tisseel are two commonly used products in this category [21, 24, 26]. These can also be aerosolized with special adapters or blowers to coat surfaces. Recently, thrombin-impregnated powders like Hemoblast have also been developed to add additional hemostasis to areas of raw surface where passive agents would typically be utilized.

When focal areas of severe bleeding occur, sheets of dual coated topical hemostatic agents can be used. Evarrest and Tachosil are fibrin sealant patches, which when applied with manual compression provide local hemostasis and can

Fig. 16.4 Surgiflo® topical hemostatic foam, available with laparoscopic applicator. (Courtesy of Ethicon Inc.)

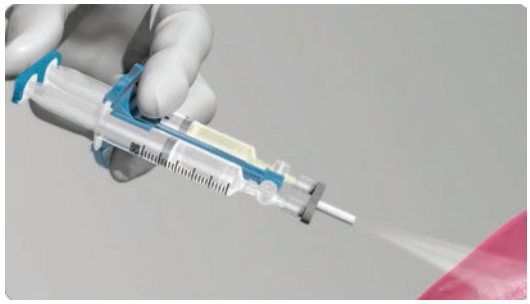

Fig. 16.5 Evicel® topical hemostatic fibrin glue. (Courtesy of Ethicon Inc.)

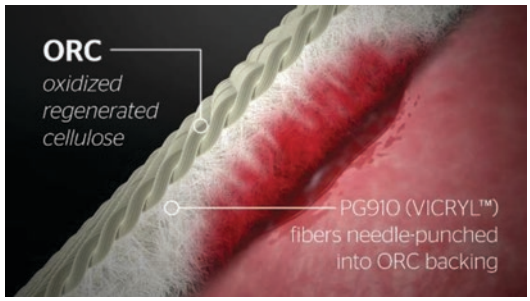

Fig. 16.6 Evarrest® dual layer fibrin sealant patch. (Courtesy of Ethicon Inc.)

Fig. 16.7 QuikClot® kaolin impregnated gauze

even be used to seal rents in large veins and arteries like the inferior vena cava or heart [7]. The patch itself has one active side coated in a powder of human fibrinogen and thrombin with a base matrix of flexible composite (Fig. 16.6). It contains oxidized regenerated cellulose which adheres to bleeding surfaces allowing it to stay in place even with higher-volume bleeding [27]. Active pressure with a wet gauze is recommended for at least 3 minutes prior to evaluating for further hemostatic needs.

There are also situations in which field hemostasis necessitates adjunct devices in the form of bandages. These include Combat Gauze (Fig. 16.7) and QuikClot, a kaolin-based inorganic product that works by the activation of factor XII [28–30]. This material can be utilized both intraoperatively directly to the site of bleeding or when necessary as a topical hemostatic. Additionally, they can be left in for 24–48 hours for damage control laparotomy for evaluation and removal of packs. Solid organ injury such as liver, kidney, and spleen and retroperitoneum can benefit from this strategy.

Depending on the site of bleeding, one of these methods of obtaining hemostasis may be best indicated. This ultimately depends on the location of patient (field vs OR), site of the injury, tools available to you (hemostatic agents, tourniquets), and familiarity upon which methods will work best for the specific injury.

Complications

It is not recommended to use these agents within closed surgical incisions as they have been known to cause complications of surgical site healing and infection. These agents should also not be used intravascularly secondary to the risk of embolization. Another complication that can commonly be seen is with quick removal of a mesh-type hemostatic agent. If unroofed too quickly, the clot that has been generated may be dislodged and recurrent bleeding may occur.

Keys to Success, Perils, and Pitfalls

The key to using any of the hemostatic agents is ensuring that the placement of the materials is at the target source of bleeding. Knowledge of the materials you have and understanding their

use are the greatest preparations for emergent situations. Powders may be a better option for generalized intra-abdominal raw surface areas with low-volume bleeding; sheets can be utilized in localized areas; bleeding while for large lacerations to the limbs or neck may be better served with QuikClot. Massive bleeding to vessels may be best served with operative repair, or if unable, a dual coated sheet may be the only option for hemostasis. All of these adjuncts rely on an intact coagulation cascade and intact and functioning platelets. Therefore, the key to success in their use is obtaining control of surgical bleeding with mechanical or electrosurgical techniques and damage control resuscitation, preferably with thromboelastography-guided transfusion.

CPT Coding

Hemorrhagic shock: R57.1

Summary

Topical hemostatics can be valuable adjuncts to control bleeding in addition to direct pressure, tourniquets, and surgical methods. A clear understanding of their limitations and uses, as well as what products are passive and what are active, is vital in successful utilization of the products.

Additional Resources

Combat Gauze: https://www.youtube.com/watch?v=bAGMa3VtrMU

Evarrest: https://www.youtube.com/watch?v=1jF5PH3moSE

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Part IV

Cardiovascular and Thoracic Procedures

Pericardiocentesis

17

Robert G. Baeten and David L. Alexander

Introduction

Pericardiocentesis is a therapeutic procedure usually performed to relieve a large, symptomatic pericardial effusion or pericardial tamponade and occasionally to identify the etiology of a pericardial effusion. Initial pericardial drainage dates back over 200 years to Romero in 1815 and the first "blind" pericardiocentesis performed by Schuh in 1840 with a trocar and cannula [1].

The etiology of most pericardial effusions correlates to the underlying clinical condition. In developed countries, up to 50% of pericardial effusions remain idiopathic despite diagnostic workup [2, 3]. Although the cause may be difficult to establish in many patients, for others it is often associated with an underlying disease [4, 5]. If clinical clues are absent, the most common etiologies of effusion are cancer (10–25%); pericarditis and infectious causes (15–30%), mainly tuberculosis (TB); iatrogenic (15–20%); and connective tissue disease (5–15%). In developing countries, >60% of effusions are related to TB [2, 6]. When the etiology is not apparent, sampling the effusion to aid has been shown to have a diagnostic yield of less than 40% [7].

Cardiac tamponade is a life-threatening compression of the heart that may occur in a slow or rapid fashion typically due to an increased volume of pericardial fluid due to inflammation or injury but may also be from clots, pus, blood, or gas [8, 9].

Clinical Features

The classic presentation of patients with pericardial tamponade includes Beck's triad of jugular venous distention from elevated systemic venous pressure, distant heart sounds, and hypotension [10]. The sensitivity and specificity of Beck's triad are limited, and there is a dearth of evidence demonstrating the diagnostic accuracy of the clinical examination for cardiac tamponade [7, 11, 12]. Although tamponade is frequently referred to as a "clinical" diagnosis, echocardiography has established itself as essential and routine in the diagnosis of pericardial effusion and the assessment of tamponade [2, 13]. Once the presence of pericardial effusion has been established, dyspnea, tachycardia, elevated jugular venous pressure, pulsus paradoxus, and

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cardiomegaly on chest radiograph are seen in over 70% of patients with tamponade [11].

Pathophysiology

The pericardium is a fibrous sac comprised of two layers, the visceral and parietal pericardium. A small amount of pericardial fluid, 20–60 mL, is normally present but is usually not noticed except occasionally in the atrioventricular and intraventricular sulcus. Pericardial fluid is an ultrafiltrate of plasma that originates from epicardial and parietal pericardial capillaries. Pericardial fluid is drained by the lymphatic system on the epicardial surface of the heart and in the parietal pericardium. An abnormal, excessive volume may develop with a variety of conditions related to increased production or impaired removal [14]. In addition to stabilizing the position, lubricating the moving surfaces, and isolating the heart from adjacent anatomic structures thereby preventing adhesions or extension of neoplasms, the pericardium functions to augment hemodynamics. By limiting heart dilatation during diastole, endomyocardial stress is reduced and negative intrathoracic pressure is preserved, which is essential for atrial filling, and the creation of a hydrostatic compensation system which ensures consistent end-diastolic pressure at all hydrostatic levels and the Frank–Starling mechanism remains functional [15].

Important in predicting tamponade are the rate of rise of the volume of pericardial fluid along with pericardial compliance. The pericardium is acutely non-compliant; therefore, even a small increase in volume can lead to hemodynamic compromise if accumulated rapidly. If excessive pericardial fluid accumulates slowly, the pericardium can stretch avoiding hemodynamic compromise. This slow accumulation will eventually reach a limit where the pericardium is unable to stretch further leading to hemodynamic collapse [16]. Tamponade develops when intrapericardial pressure surpasses intracardiac pressure resulting in impaired ventricular filling, increased venous pressure, and reduction in stroke volume [17].

Diagnosis

The primary means for confirming the presence, size, and hemodynamic effects of a pericardial effusion are via echocardiography [2]. Echocardiographic features of cardiac tamponade commonly used include diastolic collapse of the right atrium and right ventricle, ventricular shifting with respiration, and engorgement of the inferior vena cava [12] (Figs. 17.1 and 17.2). If time permits, the presence of a pericardial effusion should be evaluated by a formal echocardiogram. Although formal echocardiography remains the mainstay imaging modality, a growing consensus describes the role of point-of-care ultrasound (PoCUS) to diagnose and aid in management of pericardial effusions [16–18]. PoCUS has been demonstrated to have a high sensitivity and specificity for detection of pericardial effusion [19]. PoCUS provides diagnostic information relevant to immediate care of the critically ill patient in real time. PoCUS can identify pathologic processes and guide life-saving interventions [19].

All levels of PoCUS-trained clinicians (basic and advanced) should be able to assess for pericardial effusion and tamponade [20]. PoCUS use has expanded significantly as smaller, more portable, and affordable machines have become

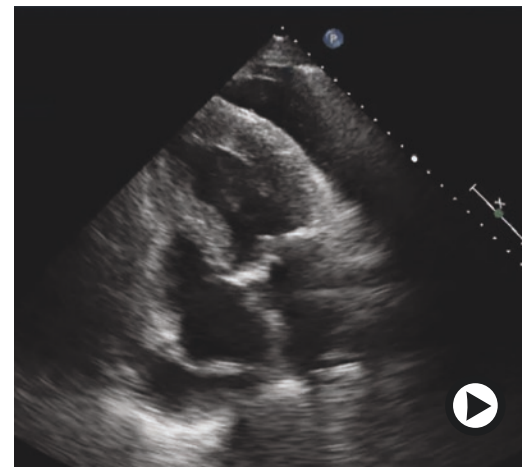

Fig. 17.1 Apical four chamber (A4C) echocardiogram with a pericardial effusion and collapse of the right atrium and right ventricle consistent with tamponade (https://doi.org/10.1007/000-2rr)

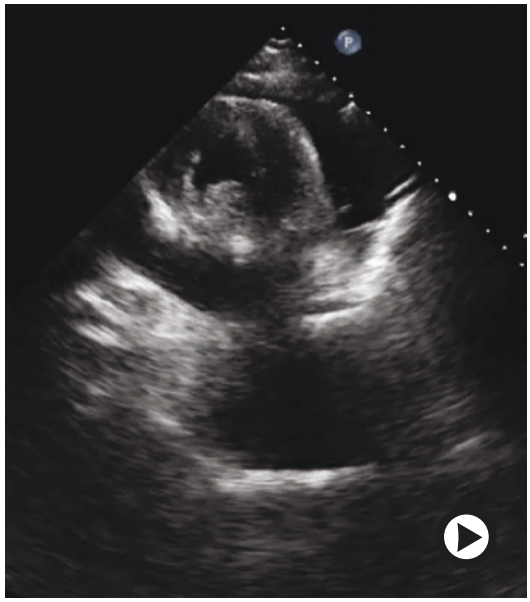

Fig. 17.2 Short-axis echocardiogram with circumferential pericardial effusion (https://doi.org/10.1007/000-2rn)

available. For advanced practice providers (APPs) which includes physician assistants (PAs) and advanced registered nurse practitioners (ARNPs), this invaluable tool can be used in a variety of clinical specialties including critical care [21]. PoCUS training has now become incorporated into many medical education programs including PA programs [22]. PAs have demonstrated competency in the use of PoCUS for diagnosis and management of pericardial effusions [23]. Even in inexperienced hands, PoCUS has been shown to be more sensitive and specific than physical exam for several conditions including pericardial effusion [24].

Fluid Analysis

Pericardiocentesis is not only therapeutic, but examination of it can aid in determining the etiology. Pericardial fluid can be categorized as transudative or exudative. Diagnosis of pericardial effusion is typically achieved by echocardiography; however, it cannot determine the etiology of the effusion. Normal pericardial fluid is clear and pale yellow. Bloody or turbid fluid suggests malignancy or infection with tuberculosis typically being bloody. A milky appearance may suggest chylopericardium.

Light's criteria, established for distinguishing transudate from exudate for pleural fluid, have a sensitivity of 98% and a specificity of 72% for identifying exudates. Pericardial effusions, like pleural effusions, may be misclassified as exudates when applying Light's criteria in the setting of diuretic therapy. Utilization of SEAG (serum-effusion albumin gradient) improves accuracy of pleural fluid analysis with diuretic therapy and may be applied to pericardial fluid analysis. Furthermore, pericardial effusion cholesterol concentrations $\geq$1.2 mmol/L improved diagnostic identification of exudates and demonstrated further accuracy when a pericardial fluid/serum cholesterol ratio was calculated [9]. Common laboratory tests on pericardial fluid include cytology, bacteriological smears and cultures, lactate dehydrogenase (LDH), protein, and cholesterol. Caution should be used when utilizing Light's criteria to pericardial fluid as the physiologically normally found high protein and LDH could lead to mischaracterization as an exudate [25]. Finally, when pericardial fluid was demonstrated to have a concentration of >40 U/L of adenosine deaminase (ADA), the sensitivity and specificity for TB were over 80% [9]. Other pericardial fluid tests to consider are viral polymerase chain reaction (PCR) and carcinoembryonic antigen (CEA) [26].

Management

Medical Management

Medical management of pericardial effusions is based on hemodynamics and underlying condition. Some effusions such as uremic effusions will often resolve with renal replacement therapy. Medical management of effusions with tamponade physiology is limited. In the setting of tamponade with hypotensive hypovolemia, IV fluids may be of limited benefit, but this has not been demonstrated in normovolemic patients [27]. In

some patient populations, diuretics, vasodilators, and mechanical ventilation should be avoided in the setting of tamponade [7, 28–30].

Procedural Management

Pericardial fluid may be evacuated from the pericardial space by either a surgical (pericardial window) or percutaneous procedure (pericardiocentesis). Both are effective; however, pericardiocentesis has been demonstrated to have a shorter length of stay and few complications [28].

Indications

According to the 2015 European Society of Cardiology (ESC) Guidelines for the diagnosis and management of pericardial diseases, Class I indications for pericardiocentesis include cardiac tamponade, symptomatic moderate to large pericardial effusions not responsive to medical therapy, and evaluation and evacuation of possible purulent pericardial effusions, to relieve symptoms and establish a diagnosis of malignancy [28]. Table 17.1 lists Class I, II, and III indications for pericardiocentesis.

In the critical care setting, hemodynamic instability from cardiac tamponade would be an indication for pericardiocentesis. Cardiac tamponade is characterized by the clinical signs of hypotension, tachycardia, elevated jugular venous pressure, muffled heart sounds, pulsus paradoxus, diminished voltage on electrocardiogram, electrical alternans of electrocardiogram, and enlarged cardiac silhouette on chest x-ray [29].

Table 17.1 ESC 2015 guidelines

Class I indication	Class II indication	Class III indication
Cardiac tamponade Symptomatic moderate to large pericardial effusions >20 mm not responsive to medical therapy Evaluate and evacuate possible purulent pericardial effusion Relieve symptoms and establish diagnosis of malignancy; perform cytology assays	Definite diagnosis of viral pericarditis Suspected tuberculosis pericarditis In the setting of aortic dissection with hemopericardium, controlled small-volume pericardial drainage for hemodynamic stabilization may be considered	As a bridge to thoracotomy with tamponade due to penetrating trauma to the heart and chest Pericardial effusion that is not responsive to patients on dialysis

Contraindications

Absolute Contraindications

In emergency situations of cardiac tamponade and shock, when hemodynamic collapse is imminent, there are no absolute contraindications. Pericardiocentesis, in these cases, is often a life-saving intervention.

Relative Contraindications

1. Coagulopathy – the risk of bleeding from pericardiocentesis is low; however, uncorrected coagulopathy is a relative contraindication.
2. Aortic dissection – normally a contraindication if thoracic surgery capability is readily available; however, a small amount of pericardial effusion may be drained from these patients to temporize hemodynamics in emergent situations [31, 32].
3. Small volume effusion – (<10 mm in diastole on echo) or when pericardial fluid is not free or when loculated in a lateral or posterior position.
4. Asymptomatic – if the pericardial effusion is small and is resolving.

Risks/Benefits

The use of direct ultrasound guidance has led to a dramatic decrease in complications [5, 33, 34]. Although there are complications inherent to pericardiocentesis (listed below), each approach offers risks and benefits.

Apical Approach

Utilizing the apical approach, there is a higher risk of left ventricular puncture; however, the wall is thicker than the right atrium and right ventricle and more likely to self-seal [35]. The pleura are usually absent over the cardiac apex making pneumothorax less likely when ultrasound is employed [36].

Subxiphoid/Subcostal Approach

The safest approach for emergent unguided approach as risk for pneumothorax is low; however, the angle of approach carries an increased risk of right atrial puncture [36].

Parasternal Approach

This approach is often provides the shortest route to the effusion; however, this approach may carry a higher risk of injury to the left internal mammary artery or pneumothorax. A puncture site above the rib is required to avoid the intercostal neurovascular bundle [36, 37].

Patient Preparation

The patient should be prepared for a pericardiocentesis as follows:

- Obtain informed consent only if time and patient condition allows.
- Review relevant laboratory data to include coagulation profile.
- To facilitate patient cooperation and ease anxiety, thoroughly explain and discuss all aspects of the procedure with the patient and family.
- Patients should be informed that the procedure may result in post-procedural discomfort.
- Remind the patient and family that, despite relatively low complication rates in ultrasound-guided pericardiocentesis, complications are possible and can be serious.
- Ensure continuous cardiac and hemodynamic monitoring. This includes blood pressure, heart rate, respiratory rate, electrocardiogram, and oxygen saturation. This is particularly important in critically ill patients.
- Use ultrasound to pinpoint or confirm the proximity of the largest effusion pocket and underlying anatomical structures.

Procedure

In addition to formal echocardiographic guidance, PoCUS devices with appropriately trained clinicians have demonstrated the capability to provide image guidance when performing pericardiocentesis [38]. As the following technique documents only the vital aspects of the three PoCUS-guided pericardiocentesis approaches, the references contain documents providing more procedural details.

General Technique

- Ensure that all necessary materials and personnel are readily available at the bedside before beginning the procedure. Clinical deterioration of the patient must be anticipated when the decision is made to proceed with a pericardiocentesis.
- If the clinical situation allows, position the patient in a recumbent 30–45 degree angle to promote inferior and apical pooling bringing the effusion closer to the anterior chest wall.
- In an anxious patient without signs of overt hemodynamic compromise, short-acting medications can be considered.
- Every effort to maintain procedural sterility must be ensured. All individuals participating in the procedure must wear sterile gloves, hat, mask, and gown.

- Ensure the ultrasound probe is placed in a sterile sheath.
- Antiseptically prepare the skin from the chest to the abdomen using a chlorohexidine-based solution and then drape the site with sterile towels.
- Anesthetize the skin at the selected site with a local anesthetic.
- Use a local anesthetic and a small gauge needle to anesthetize along the anticipated trajectory. Use ultrasound guidance for this to avoid potential injury to underlying anatomical structures.
- Using continuous ultrasound guidance, carefully advance a sheath-covered needle attached to a saline-filled syringe toward the pericardium, while using gentle continuous negative suction, until the pericardial sac is entered and fluid is obtained.
- Once fluid is obtained, gently advance the sheath over the needle and withdraw the needle.
- Confirm placement of the needle in the pericardial space by injecting agitated saline through the catheter under direct ultrasound visualization, observing for formed microbubbles in the pericardial sac (Figs. 17.3 and 17.4).
- Gently advance guidewire through the sheath and then remove the sheath over the guidewire (Figs. 17.5 and 17.6).

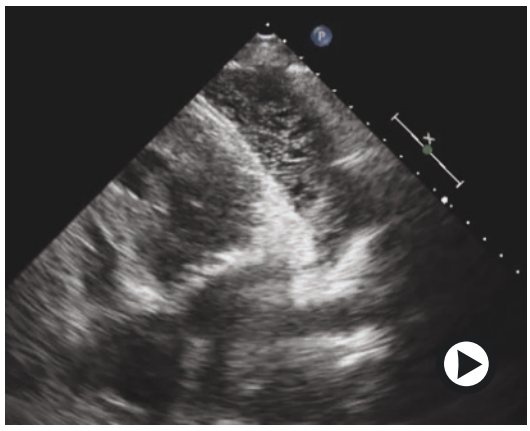

Fig. 17.3 A4C view injecting agitated saline through the catheter under direct ultrasound visualization, observing for formed microbubbles in the pericardial sac. (https://doi.org/10.1007/000-2rp)

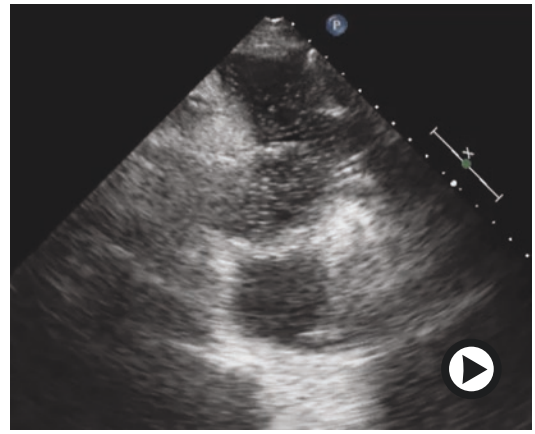

Fig. 17.4 Short-axis injecting agitated saline through the catheter under direct ultrasound visualization, observing for formed microbubbles in the pericardial sac. (https://doi.org/10.1007/000-2rq)

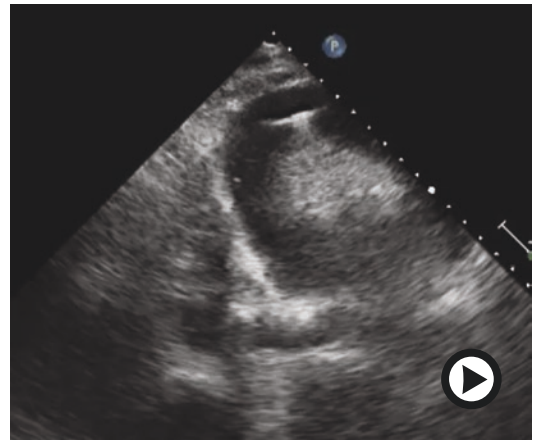

Fig. 17.5 Hybrid views to visualize the guidewire within the pericardial space (https://doi.org/10.1007/000-2rm)

- Make a small "nick" incision at the wire insertion site and then gently introduce the dilator over the wire.
- Remove the dilator over the guidewire and then insert the catheter over the guidewire (Figs. 17.7 and 17.8).
- Inject agitated saline again into the pericardial sac to confirm placement of the catheter.
- Drain the pericardial fluid using gentle syringe suction (Fig. 17.9).
- Remove catheter and hold pressure at the site.
- Obtain follow-up echocardiogram and CXR.
- Provide low-dose analgesics if the patient is hemodynamically stable.

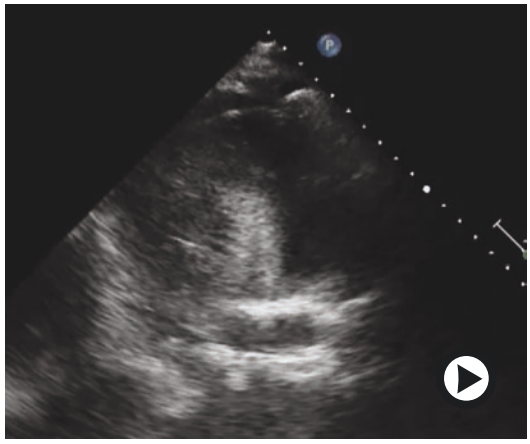

Fig. 17.6 Hybrid views to visualize the guidewire within the pericardial space (https://doi.org/10.1007/000-2rs)

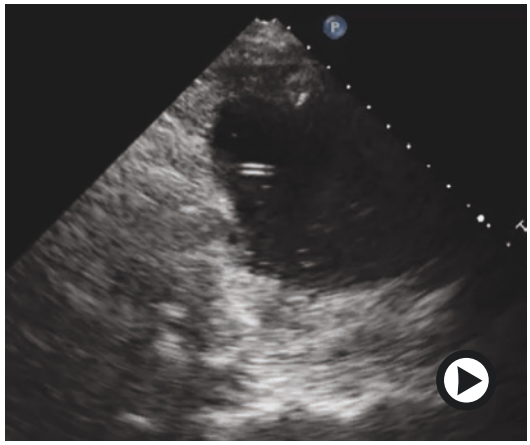

Fig. 17.7 Hybrid view demonstrating presence of catheter within the pericardial space (https://doi.org/10.1007/000-2rt)

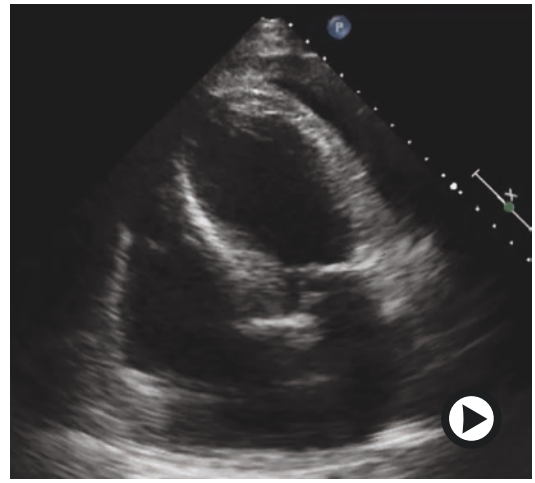

Fig. 17.8 A4C view of catheter in pericardial space (https://doi.org/10.1007/000-2rv)

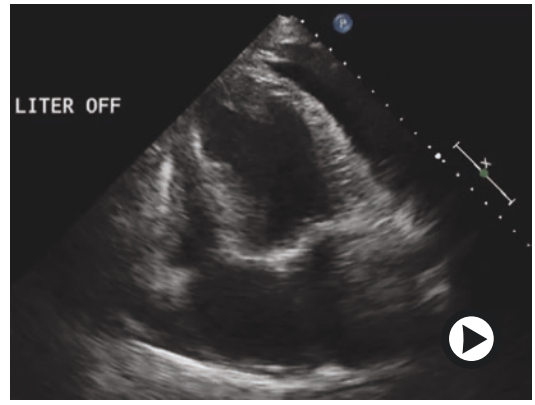

Fig. 17.9 A4C view demonstrating removal of 1 l of pericardial fluid (https://doi.org/10.1007/000-2rw)

Specific Techniques

PoCUS-Guided Subxiphoid/Subcostal Technique

Using a 30-degree angle, insert the sheathed needle into the skin below the xiphoid process and 1 cm to the left of the costoxiphoid angle (Fig. 17.10). Using continous ultrasound guidance, identify the site of the largest effusion and any underlying structures. With the transducer pointed under the xiphoid process and aimed cephalad, slowly advance the sheathed needle toward the left shoulder while maintaining gentle continuous negative suction. Once fluid is obtained and the catheter is in place, connect the syringe and catheter to a drainage bag via a three-way stopcock. Completely drain pericardial fluid by manual syringe suction. Continue to assess the patient for hemodynamic stability.

PoCUS-Guided Apical Technique

Palpate for the apex and use PoCUS to identify the site of the largest apical effusion and any underlying structures. Using continuous ultrasound guidance, with the transducer placed just inferior and lateral to the left nipple, insert the sheathed needle into the intercostal space below and 1 cm lateral to the apical beat (Fig. 17.11). Slowly advance the sheathed needle toward the

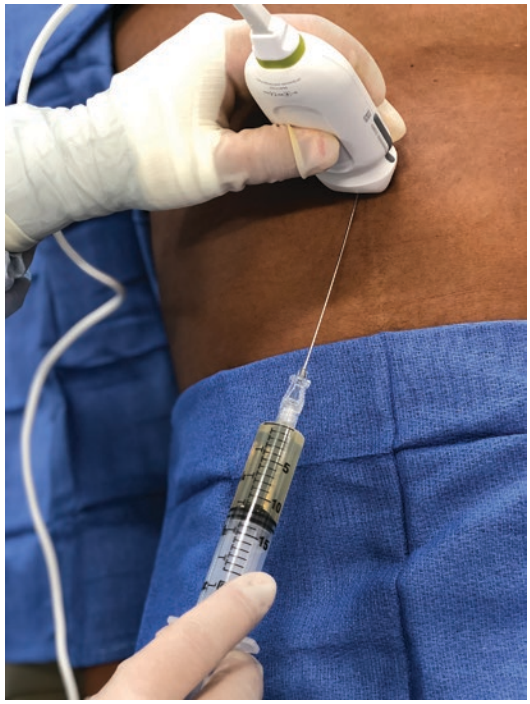

Fig. 17.10 Subxiphoid/subcostal technique

Fig. 17.12 Parasternal technique

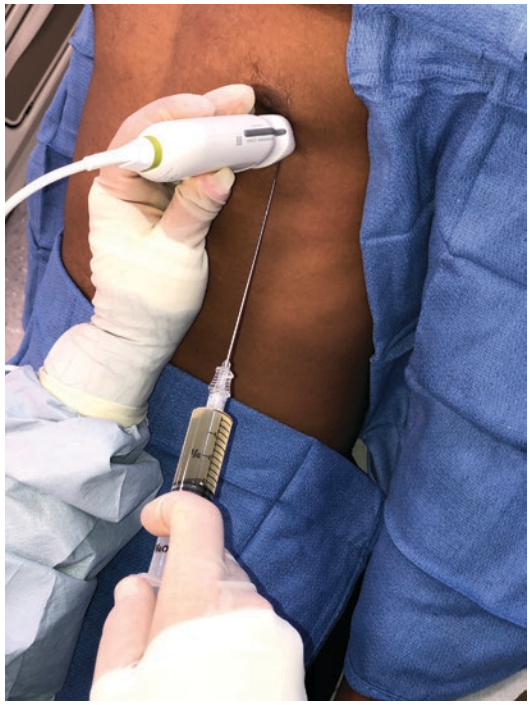

Fig. 17.11 Apical technique

right shoulder while maintaining gentle continuous negative suction until fluid is obtained.

PoCUS-Guided Parasternal Technique

Use PoCUS ultrasound to identify the site of the largest parasternal effusion and underlying structures. Using continuous ultrasound guidance, with the transducer left of the sternum in the third or fourth intercostal space, insert the sheathed needle perpendicularly into the fifth intercostal space 1 cm lateral to the sternal border (Fig. 17.12). Slowly advance the sheathed needle over the upper border of the rib while maintaining gentle continuous negative suction until fluid is obtained.

Equipment (Figs. 17.13, 17.14, and 17.15)

Pericardiocentesis Tray:

- Skin antiseptic – (Chloraprep or povidone-iodine)
- Sterile Transparent Fenestrated Drape

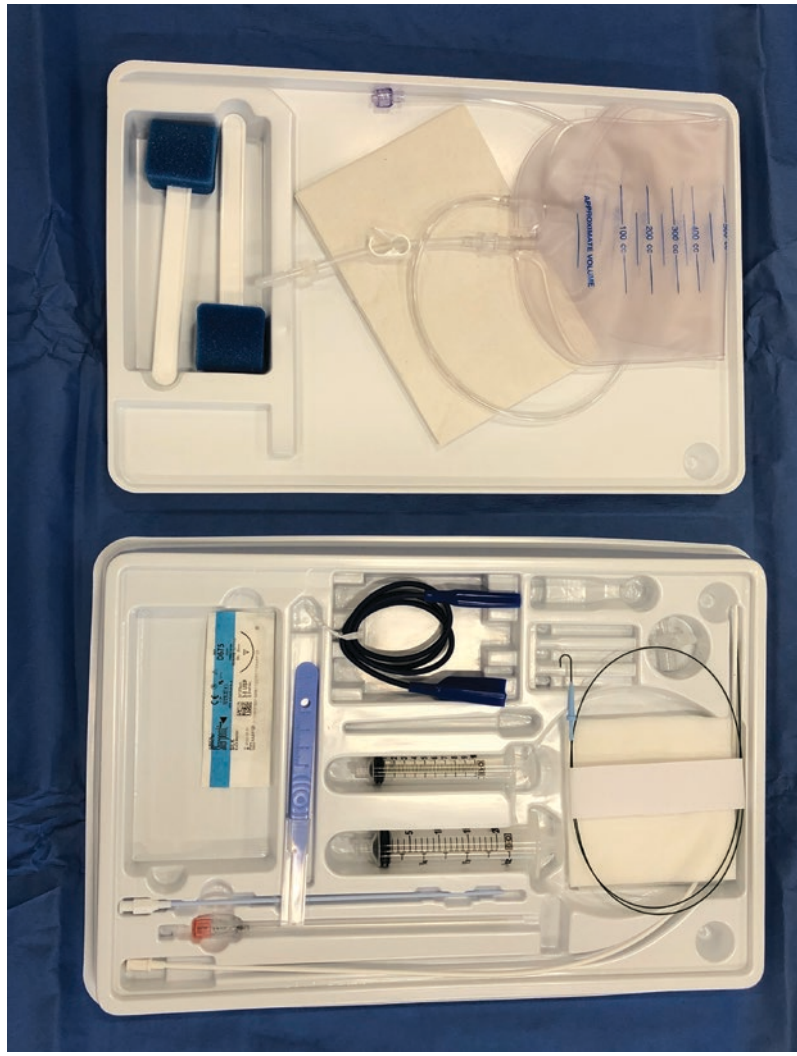

Fig. 17.13 Pericardiocentesis tray

- One 20–25G needle for local anesthesia infiltration
- Local anesthetic (e.g., 1–2% lidocaine)
- Scalpel – #11 Blade
- 4 × 4 Gauze
- 18-gauge Teflon-sheathed needle (with a length of 5–8 cm)
- Syringes – 10, 20, and 50 mL
- 0.035 mm J-tipped guidewire of sufficient length
- 5F to 8F dilator or introducer sheath

Other Supplies:

- Echocardiography with phased array probe (however, curvilinear and in some instances a linear probe may be used)
- Sterile gown and gloves
- Sterile mask and surgical cap/bouffant
- Sterile isotonic saline for bubble confirmation and catheter flush
- Sterile probe cover with sterile ultrasound gel
- 5F to 8F, 65 cm pigtail catheter with multiple side holes

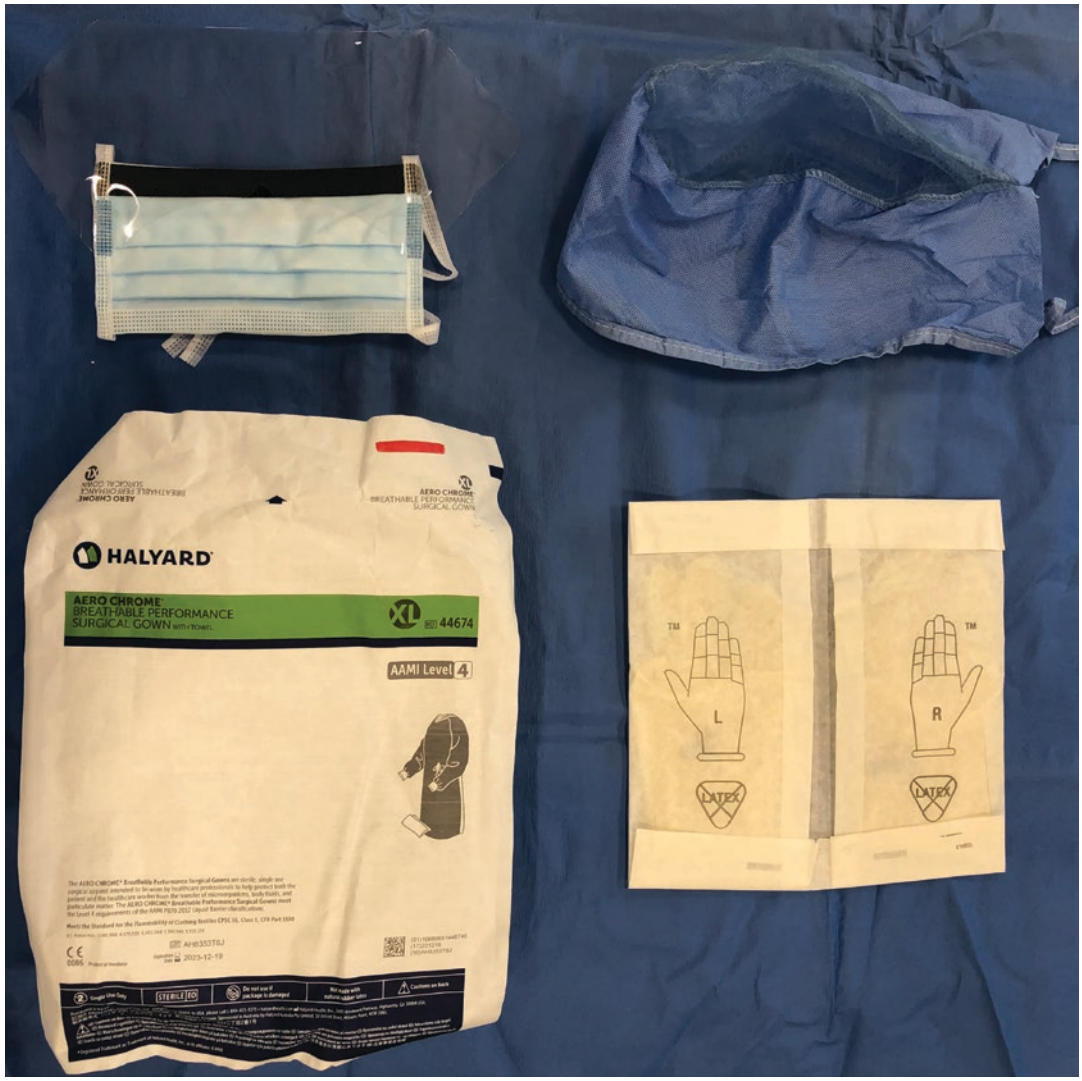

Fig. 17.14 Sterile personal protective equipment

Complications

Major complications for echo-guided or fluoroscopic-guided pericardiocentesis range from 0.3% to 3.9% with minor complications ranging from 0.4% to 20%. Major complications include death, laceration of the coronary arteries or intercostal vessels, injury of the cardiac chambers, ventricular arrhythmias, pneumopericardium, pneumothorax requiring chest tube placement, puncture of abdominal organs, and pericardial decompression syndrome [17, 35, 39, 40].

Pericardial decompression syndrome is a rare but potentially fatal syndrome with a 30% mortality that is characterized by hemodynamic deterioration and/or pulmonary edema after an uncomplicated pericardial drainage and is often associated with unexplained development of ventricular dysfunction with an onset of 1–2 days. The mechanism remains poorly understood but may be related to abrupt withdrawal of the entire effusion, and a proposed preventative measure is to initially remove enough pericardial fluid to relieve tamponade and then to prolong the drainage via a drainage catheter [41, 42].

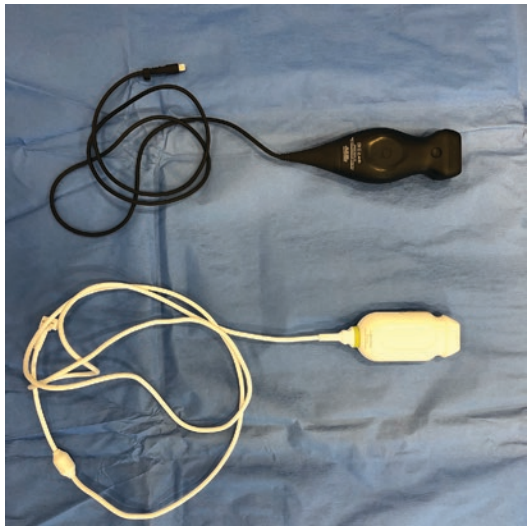

Fig. 17.15 PoCUS probes

Although this has become less common, electrocardiographic monitoring with an electrode attached to the needle for guidance (ST elevations seen when needle contacts myocardium) has fallen out of favor as the risk of current leak could induce ventricular fibrillation [43].

Minor complications include supraventricular arrhythmias, pneumothorax without hemodynamic sequelae, and temporary vasovagal hypotension [34].

Keys to Success, Perils, and Pitfalls

Intracardiac blood will clot, whereas blood that has transmigrated into the pericardial space will not as it is fibrin free [44]. Two common false positives which can be mistaken for a pericardial effusion by users of PoCUS include pleural effusion and pericardial fat pads. To distinguish a pleural effusion, the descending aorta may be used as a landmark in the parasternal long-axis view. A pericardial effusion will be anterior, whereas a pleural effusion will be inferior to this structure. Concerning a pericardial fat pad, pericardial fluid is typically anechoic, while a fat pad will appear echoic and may have a mottled appearance. Additionally, fat pads also move in concert with the myocardium without competing with the cardiac chambers for space within the pericardium [15] [45]. Finally, difficult pericardiocentesis should be anticipated in patients with prior median sternotomy, obesity, cardiac chamber enlargement/dilation, or loculated pericardial effusions [46].

CPT Coding

- 33010. Pericardiocentesis; initial
- 76930-26. Ultrasonic guidance for pericardiocentesis, imaging supervision, and interpretation; professional component
- 93308-26. Transthoracic echocardiogram; limited or follow-up

Summary

Pericardiocentesis is an important, potentially life-saving procedure that is no longer limited to cardiologists [47]. The diagnosis of tamponade or significant pericardial effusion should be established in a timely fashion. PoCUS, which includes cardiac ultrasound, can be expeditiously performed by APPs [48]. Effective management is essentially limited to pericardial fluid evacuation as the use of volume expansion may be of little benefit and potentially harmful [27]. Procedural guidance with ultrasound is often readily available, even in resource limited settings [49].

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18 Temporary Transvenous and Transcutaneous Pacemakers

Krista J. Allshouse and Richard S. Musialowski

Introduction

Temporary pacing is a technique used in emergent situations when cardiac output is not adequate for tissue perfusion due inadequate heart rate. It may be used until the underlying problem resolves or until a permanent device can be implanted. Temporary pacing may also be used electively, perioperatively, or in the setting of an acute MI to support hemodynamics or to facilitate management of arrhythmias. Symptoms of bradycardia include dizziness, syncope, chest pain, shortness of breath, fatigue, weakness, confusion, and decrease in exercise capacity. There are multiple EKG manifestations of bradycardia including sinus bradycardia, various types of heart block, pauses, and escape rhythms. Temporary pacing can be undertaken by externally pacing with electrode patches placed on the chest (transcutaneous), by placing a temporary pacing wire into a patient's right heart (transvenous), or with wires placed into the epicardium at the time of cardiac surgery.

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Pacing Basics (Table 18.1)

Temporary pacing provides an electrical stimulus to the heart to produce mechanical contraction. Pacing, whether temporary or permanent, uses NBG nomenclature (NASPE and BPEG together) to specify the mode of pacing. The first letter indicates the chamber paced; the second indicates the chamber sensed; the third letter indicates the response to sensing, i.e., inhibition (withholding an impulse). A few common modes are VVI in which the ventricle is paced and sensed and the pacer will inhibit if it senses an intrinsic beat. This is the most commonly used mode for temporary pacing as it avoids possible asynchronous pacing into a T wave, initiating Torsades. VOO, on the other hand, is asynchronous pacing and paces the ventricle but does not

Table 18.1 Nomenclature for pacing

NASPE/BPEG Generic Code for Pacing			
Position:	I	II	III
Category:	Chamber paced 0 – none A – atrium V – ventricle D – dual (A + V)	Chamber sensed 0 – none A – atrium V – ventricle D – dual (A + V)	Response to sensing 0 – none T – triggered I – inhibited D – dual (T + I)

Based on data from Revised NASPE/BPEG Generic Code for Antibradycardia, Adaptive-Rate, and Multisite Pacing, *Journal of Pacing and Clinical Electrophysiology*, 2002; 25(2):260–4

D. A. Taylor et al. (eds.), *Interventional Critical Care*, https://doi.org/10.1007/978-3-030-64661-5_18

sense intrinsic beats or inhibit. This is commonly used if the patient has no underlying rhythm. Other common modes are atrial including AAI and AOO. DDD (dual chamber), in which both chambers are paced and sensed, is the most common mode for epicardial systems. Modes are selected on the pacing box.

In addition to a mode being set, temporary systems need to have three settings programmed – pace rate, output, and sensitivity. The pace rate is the number of beats per minute with 60–100 bpm being normal for the average adult. This can be adjusted to optimize cardiac output. *Capture* is when the electrical stimulus provided by the device consistently produces a cardiac muscle contraction. Capture must be ensured by evaluating the EKG for a pacing spike followed by depolarization (usually a wide QRS is seen with ventricular pacing) and needs to be checked at least daily. *Output* or *pacing threshold* is the minimum amount of energy it requires to produce a cardiac contraction. *Sensitivity* is what the system "sees." The lower the number on the sensing dial, the more sensitive. The more sensitive the setting, the more it will sense underlying electrical impulses, allowing more intrinsic conduction to occur. This may allow the device to inappropriately inhibit due to artifact and cause bradycardia despite the presence of a temporary wire. This can lead to symptoms of low cardiac output including shortness of breath, weakness, edema, dizziness, etc.

Types of Pacing

Transcutaneous pacing is quick, is noninvasive, and requires little training to place. It is painful as it requires higher energy output for capture with electricity going through the chest wall to reach the heart. Skin burning and skeletal muscle contraction with pacing necessitate patient sedation. This form of pacing should only be used in extreme emergencies such as in the pre-hospital setting or very temporarily (ideally less than 2 hours) in an emergency until more definitive therapy can be undertaken in a deeply sedated or unconscious patient. Outputs can be affected by obesity, ischemia, metabolic derangements, electrode contact, and pneumothorax. At times it is hard to ensure capture on EKG due to pacing artifact with the amount of energy required. We recommend confirming capture by checking pulses or looking at arterial or pulse oximeter waveform to ensure pulsatile flow.

Transvenous pacing requires central venous access and has an increased risk of infection. Loss of capture or sensing with movement can occur due to dislodgement of the wire. It also cannot be completed as rapidly as transcutaneous pacing. Multiple sites can be considered for temporary pacemaker placement, but the most common sites used currently are femoral and internal jugular. Femoral access may require fluoroscopy or ultrasound to place and impedes patient movement after insertion. While the catheter is in place, the patient needs to lay flat with the leg extended on strict bedrest. Femoral access may be preferred if the patient has a coagulopathy to ensure ability to compress the vessel if bleeding were to occur. It is also commonly used in the setting of an MI and placed in the catheterization lab. The right internal jugular (IJ) site is preferred as the femoral vein site is associated with increased infection risk. The right internal jugular vein provides direct access to the right ventricle with high success rate and low complication risk. Although it is possible to complete a blind insertion, decreased risk and better capture is seen with placement under fluoroscopy. This procedure is usually, and most safely, completed by an interventional cardiologist or electrophysiology physician in the cardiac catheterization laboratory. The temporary pacing wire can be placed in the atrium, ventricle, or both. Fluoroscopy should always be used in patients with tricuspid valve disease, if the patient is anticoagulated or if the patient has an underlying left bundle branch (LBBB). If the patient has a LBBB, there is a risk of the catheter contacting the right bundle and causing transient complete heart block.

Epicardial pacemaker wires are often used postoperatively after cardiac surgery. Commonly, post-operative bradycardia can result from inflammation causing AV block, bundle branch block, fascicular block, or sinus node disease. It is

important to check pacing and sensing thresholds daily in postoperative patients as these thresholds tend to degenerate over the first 3–5 days after placement. These wires are then pulled when they are no longer needed or decision to place a permanent device is made.

Indications

The main determinants of treatment for bradycardia are symptoms or hemodynamic compromise with hypotension. These indications may be emergent or elective. Many factors may induce or exacerbate bradycardia or preexisting conduction disease causing the need for temporary pacing. Multiple medications affect the conduction system including antihypertensives, antiarrhythmics, psychoactive drugs, and many others. Trauma, surgery, medical comorbidities, congenital heart disease, cardiomyopathies, and ischemia may affect cardiac conduction. Multiple rhythms caused by either sinus node dysfunction or AV nodal disease may create the need for pacing. If the QRS complex is narrow during the bradycardia, AV nodal disease is more likely. A wide complex escape is more concerning and often requires pacing intervention. HIS-Purkinje localized bradycardia (second-degree Type 2 or third-degree heart block) will not respond to medications and will usually require pacing. Vagally mediated bradycardia usually shows progressive sinus slowing, progressive PR prolongation, or Mobitz Type 1 second-degree block prior to the onset of complete heart block. It is often treated with medications to increase the heart rate, rather than pacing. Bradycardia with neurologic causes, hypothyroidism, hypothermia, and seizures almost never require temporary pacemaker placement. In all causes of bradycardia with symptoms, the elimination of offending conditions and medications should be attempted before more invasive measures are taken.

Examples of second-degree Type 2 and third-degree heart block (Figs. 18.1 and 18.2, Table 18.2):

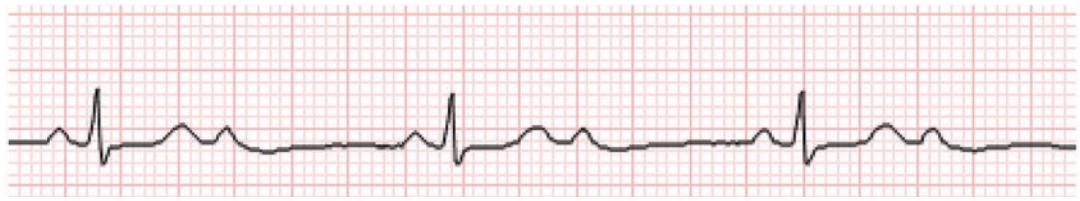

Fig. 18.1 Second-degree Type 2 heart block: 2:1

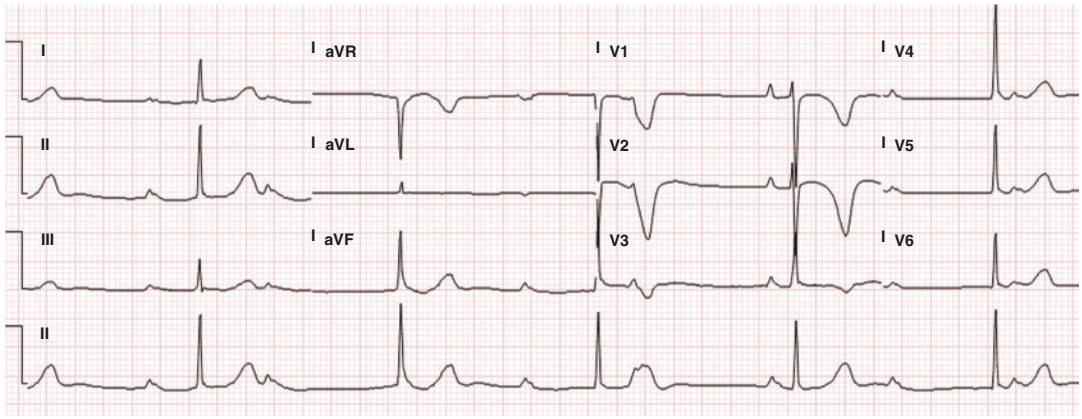

Fig. 18.2 Complete heart block (third degree)

Table 18.2 Temporary pacemaker indications

Indication	Rhythm	Cause
Sinus node disease	SSS/sinus pauses Tachy-brady syndrome	Acute MI-RCA Vagal Medications
AV node disease	Second-degree HB Third-degree heart block New BBB or bifascicular block with MI	MI – anterior wall Infections – Lyme, perivalvular abscess, myocarditis Ischemia Medications Metabolic derangements – hypocalcemia, hyper-/hypokalemia, hypomagnesemia
Special circumstances		Electively for surgery Brady/pause-dependent VT Overdrive pacing of ventricular arrhythmia Pacemaker explant Long QT syndrome

Based on data from Revised NASPE/BPEG Generic Code for Antibradycardia, Adaptive-Rate, and Multisite Pacing, *Journal of Pacing and Clinical Electrophysiology*, 2002; 25(2):260–4

Contraindications

Contraindications for transvenous pacemaker wire placement include mechanical tricuspid valve, known vena cava stenosis, or RV infarction due to increased risk of perforation of the infarcted myocardium. MRI cannot be completed once temporary pacing wire is in place.

Transvenous Pacing

- Carry risks associated with central venous line placement including inadvertent arterial placement, bleeding, pneumothorax, arrhythmias, infection, and unsuccessful attempts.
- Placement of wires may lead to arrhythmia, injury to valves and cardiac structure, pericardial effusion or injury to myocardium, malposition of wires, as well as failure to capture.

Benefits

Provide stabilization of cardiac brady arrhythmias that are potentially life-threatening and may cause additional clinical deterioration and may lead to death or serious morbidity.

Preparation

Equipment needed for temporary transvenous pacemaker insertion includes venous access kit, patient sedation, sterile gloves, drapes, gown, mask, eye protection, anesthetic, pacing lead, connector cable, and pulse generator, i.e., "pacer box." Temporary transcutaneous pads should be placed during the procedure for safety. The type of device used is determined by the urgency of the situation, stability of device, duration of need for pacing, availability of fluoroscopy, patient characteristics, and experience of the operator. Many operators have documented lower risk if fluoroscopy is used. One recent study documented higher risk in teaching centers and more urgent cases so urgency of pacing must be weighed with potential for complications [1]. Cardiology should be involved as soon as possible.

There are many companies that make pacing systems with Medtronic and Biotronik versions used commonly in the USA. Various types of temporary leads are available including bipolar leads which have both negative and positive electrodes in contact with the endocardium and unipolar leads which have negative electrode in contact with the endocardium and another pole elsewhere in the body. Unipolar leads tend to have more problems with oversensing and are not commonly used. There are semi-rigid leads that are only placed with fluoroscopy and floating balloon-tipped catheters used for bedside insertion. For the most part, temporary pacing is accomplished with either type of bipolar lead placed into the RV apex. If ventricular pacing causes decreased cardiac output due to loss of atrial kick, then an atrial wire can additionally be placed to maintain synchrony. Temporary pacemaker wire is attached to the adapter, which

plugs into the pacer box. Dual-chamber devices are primarily used in the post-operative setting and are epicardial. Each epicardial wire is attached to a connector block that supplies the connecter pins that plug into the pacemaker box itself. Adapter pins (black and red) may also be placed over the distal ends of the wire and then plugged into the red and black adapters that plug directly into the pacing box (Figs. 18.3, 18.4, 18.5, and 18.6).

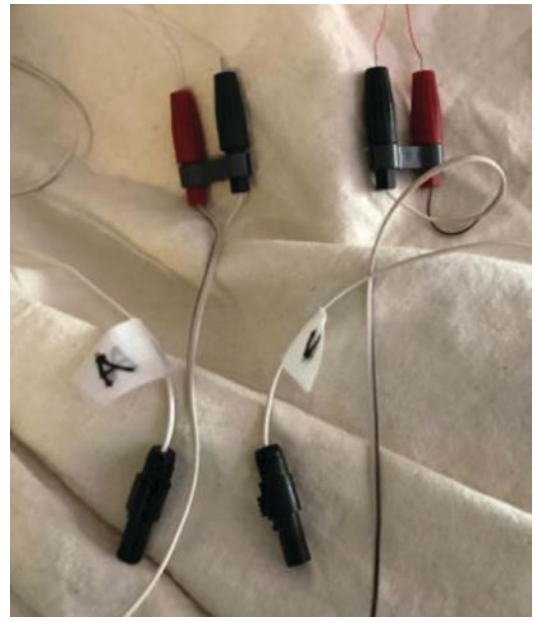

Fig. 18.4 Atrial and ventricular connecters from epicardial leads that will then get plugged into the pacer box

Procedure

Transcutaneous pacing requires only pacing pads, EKG leads, and an external defibrillator (Fig. 18.7). Skin should be prepared by cleaning with alcohol and shaved to ensure pacer pad adherence. Anterior electrode pad (negative polarity) should be placed over the cardiac apex or point of maximum impulse, and the posterior

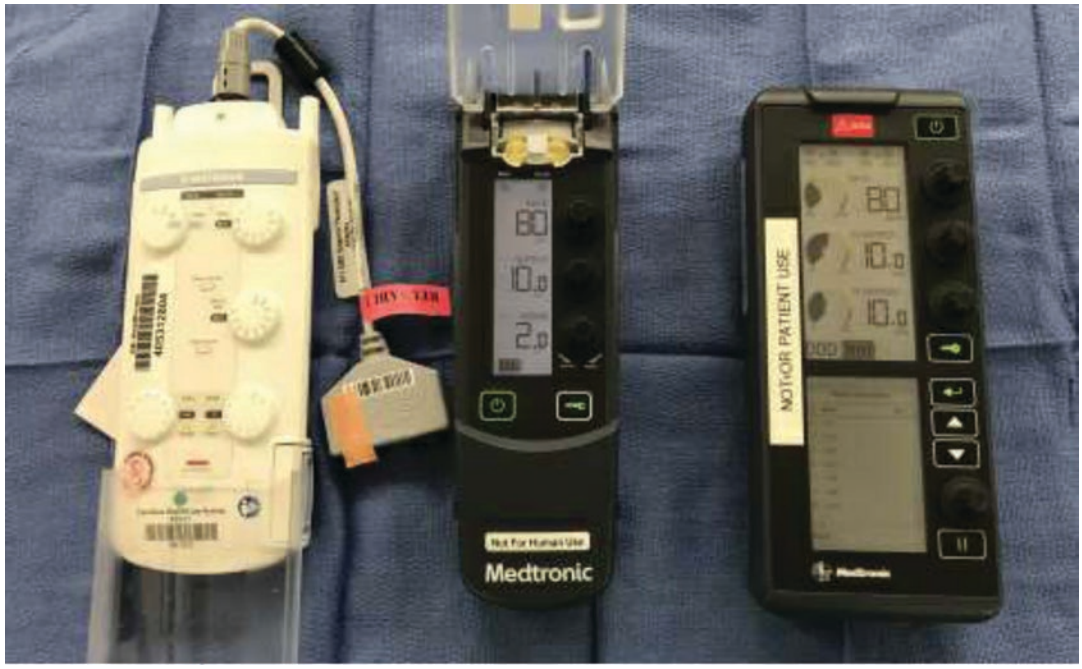

Fig. 18.3 Transvenous pacing boxes. The first two are single chamber and the third (right) is dual chamber

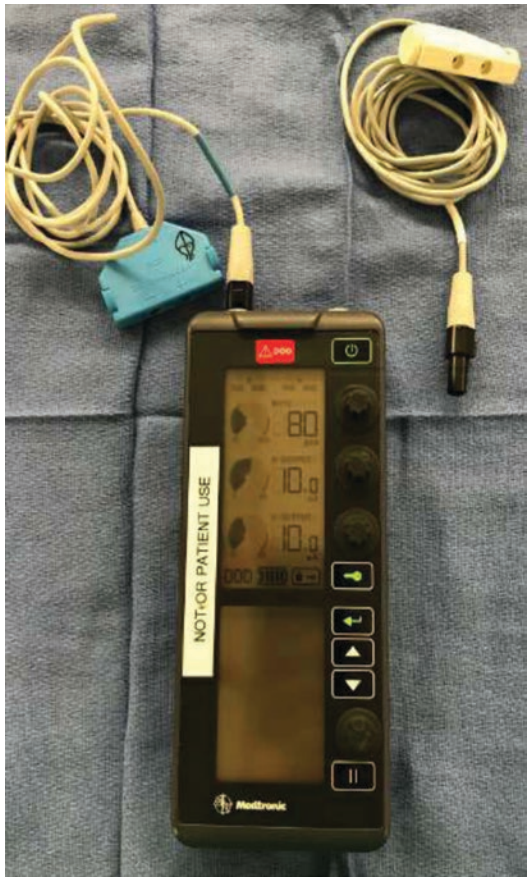

Fig. 18.5 Dual-chamber temporary pacemaker box, epicardial atrial connecter on the left, ventricular connecter on the right

pad (positive polarity) should be placed posteriorly, inferiorly to and between the scapula. Pacing pads are attached to the defibrillator and device is set to pacing mode. Pacing should be initiated at maximum output in asynchronous mode in an emergency to ensure capture, which can then be decreased to 5 to 10 milliamperes (mA) above threshold. If it is not an emergency, output can be initiated at the lowest output setting and gradually increased until capture is seen. Most manufactures have a set rate and output that device is set to when turned to pacing mode. Rate should be programmed to 10 beats per minute above patient's intrinsic heart rate. Blood pressure, heart rate, level of consciousness, and pulse should be assessed regularly. If pads must be in place for an extended period, they should ideally be changed every 8–12 hours. Again, verify capture by checking for an adequate pulse on the patient.

Both IJ and femoral temporary pacing wires are placed under sterile technique. The patient is given sedative medication and the site is anesthetized with local anesthetic. Central venous access should be obtained in the usual sterile fashion, and then a transvenous wire is inserted through an introducer. It is important that the correct size wire is used with the correct introducer (5 French (fr.) wire goes with a 6 fr. introducer). This prevents leakage around the site. If completing transvenous insertion at bedside without fluoroscopy, a balloon-tipped catheter is advanced to the RV under EKG guidance until ventricular capture is seen. Catheter should be set to pace faster than patient's intrinsic heart rate and the balloon is deflated after capture is ensured. The wire should be advanced slightly after the balloon has been deflated to ensure adequate contact with the myocardium. More commonly, the wire is advanced under fluoroscopy into the right atrium or ventricle through venous sheath and capture is ensured. Capture can be ensured with EKG and pacemaker programmer or using the pacing box and will show a pacing spike immediately followed by a wide QRS. Passive fixation leads lodge into the endocardium and active fixation leads are screwed into the endocardium. Active fixation leads (regular transvenous pacemaker leads) are only implanted under fluoroscopy due to higher risk of perforation. The best positioning of the lead in the RV is the inferior or septal border 2/3 the distance to the apex as this will ensure the best thresholds and minimize ventricular ectopy. Pacing rate is usually set at 10–15 beats above intrinsic HR. Output is started at 5 mA and decreased until capture is lost. Output is then set at 2–3 times the value where capture was lost. This is called a safety margin. Ideally, output should be less than 1 mA. For example, if the device captures at 1 mA, then the pacer should be set at 2–3 mA for adequate safety margin. The wire is secured with a loop of redundancy

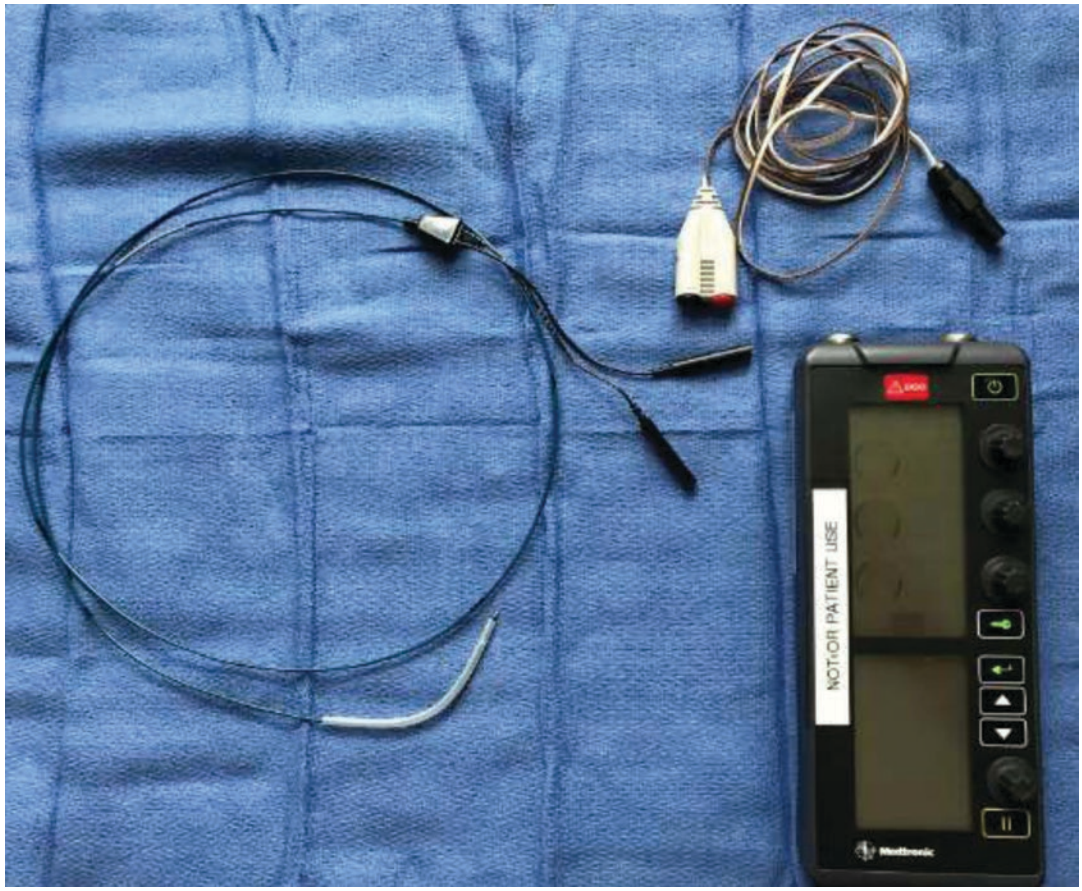

Fig. 18.6 Temporary transvenous pacing wire on the left. The upper right is the connecter. Temporary pacing box is on the lower right.

to the skin with sutures and occlusive bandage placed. The temporary pacing wire or epicardial (post-surgical) wires are attached to a temporary pacing box through the connector. A "temporary permanent" (temp-perm) pacemaker may also be placed with an active fixation lead through the IJ approach that is then secured to a permanent pacer generator secured to the outside of the neck. There is also an adapter that can be plugged into the end of the pacing wire to attach to a pacing box. This will allow the patient to be more active without risking dislodgement of the device. These devices are traditionally used by patients who have a permanent device removed, are pacer dependent, and/or are awaiting replacement of the device. This type of device can be used for weeks and ensures mobility of the patient and stability of pacing when a device is removed for infection, requiring a course of antibiotics prior to reimplantation. This must be implanted in the catheterization lab under fluoroscopy. Trouble-shooting of this active fixation wire is the same as traditional transvenous leads.

Epicardial pacemaker wires are often used in the perioperative setting. Pacing is accomplished by wires sutured to the epicardium of both the anterior atrium and ventricle during surgery, tunneled out through the skin, and secured with sutures to the skin surface. The atrial wire is on the right and ventricular wire is on the left of the sternum. These are then attached to a connector and pacing box.

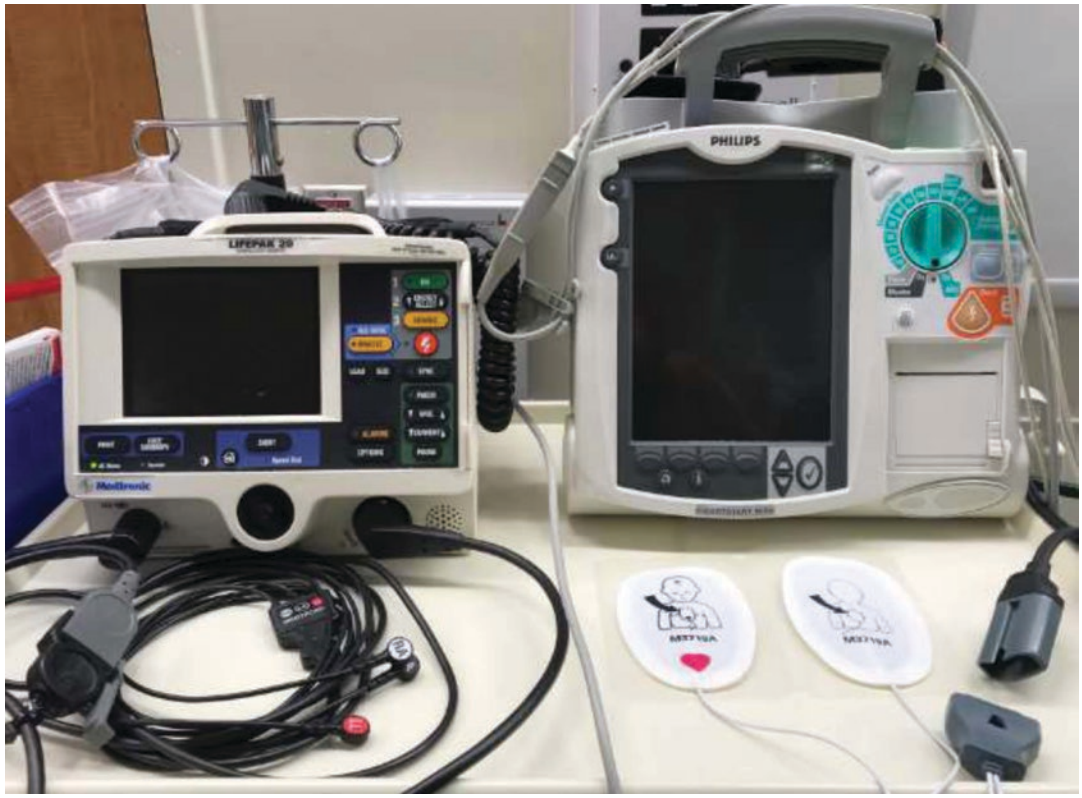

Fig. 18.7 Pacing can be accomplished with these defibrillators and pacing pads

Complications

Potential complications of a transvenous device include lead dislodgement, arrhythmia, perforation (tamponade), bleeding/hematoma, and pneumothorax. Chest X-ray to ensure correct placement should be completed immediately after the procedure and any time there is a major change in pacing thresholds (Fig. 18.8). This will also evaluate for pneumothorax. If the patient has jerky abdominal movements or hiccups noted after insertion, diaphragmatic pacing is occurring. Tamponade should be ruled out with echo and lead repositioned. IJ site is preferred due to increased infection risk with femoral access. Epicardial wire complications may include infection and possibility of tamponade when wires are pulled. Temporary leads often lose capture and develop high thresholds much faster than traditional transvenous leads.

Temporary pacemaker capture and sensing thresholds should be evaluated at least daily. Issues that can arise with temporary pacing include under- or oversensing, loss of capture, or loss of output. There may also telemetry abnormalities due to pacing such as dropped beats or fusion seen.

Troubleshooting

Telemetry should be evaluated to ensure capture with a QRS complex seen immediately following each pacing spike. Loss of capture may also result from MI, electrolyte abnormalities, hypoxia, or acidosis. Loss of capture could also be from lead fracture or dislodgement or system failure. To test capture threshold, device should be programmed to 10 bpm above intrinsic heart rate. Output should be increased until consistent capture is seen. Slowly decrease output, watching the monitor for a pacer spike with no QRS following (Fig. 18.9). This is the point of loss of cap-

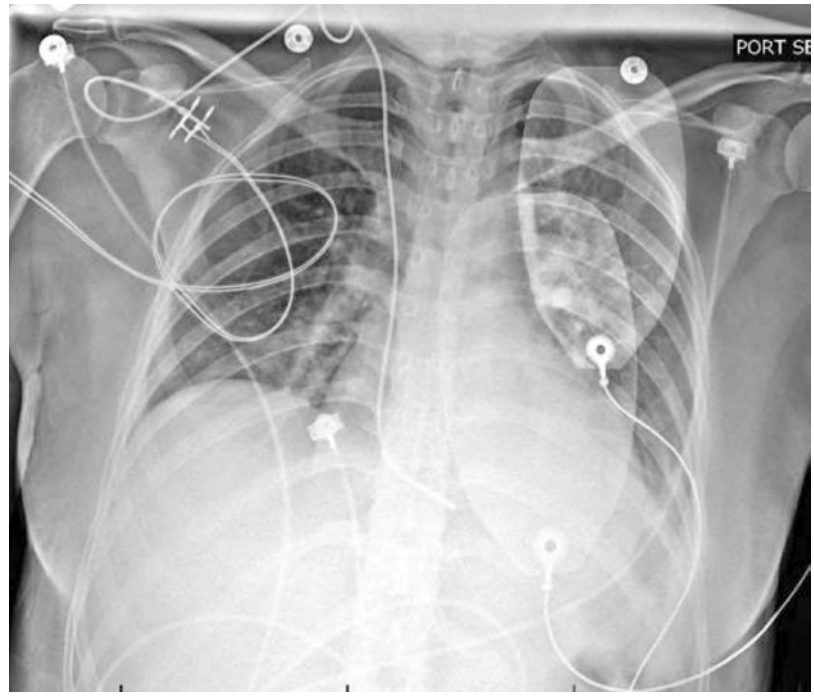

Fig. 18.8 X-ray showing temporary pacemaker placement in the right ventricle. Patient has transcutaneous pacing pads on also in the upper left

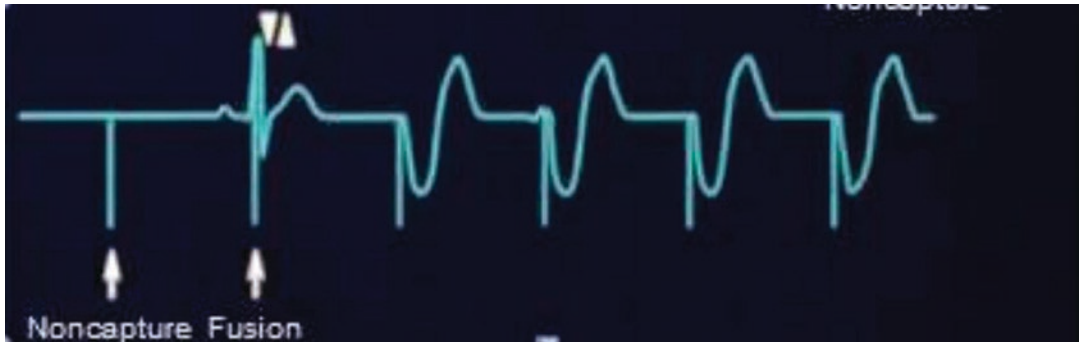

Fig. 18.9 EKG demonstrating progression of non-capture followed by capture of patient being paced

ture. Output should be programmed at 2–3 times the value of consistent capture. Output failure is seeing no pacing spike when there should be one or lower heart rate than programmed. This may mean the output is not adequate, lead or system failure, or lead dislodgement.

Intrinsic cardiac electrical activity should also be evaluated. To see if there is an underlying rhythm, the pacing rate can gradually be decreased to see if the patient's intrinsic rhythm comes through.

To test sensing, set pacing rate 10 bpm below patient's intrinsic rate. Note that patient may become symptomatic if no underlying rhythm comes through. Decreasing rate should be done gradually to limit patient symptoms from bradycardia. If patient becomes symptomatic at low rate with no underlying rhythm, sensitivity testing should be deferred. Sensitivity should be turned to minimum value of 0.5 mV (most sensitive) initially and increased until pacing spike is seen on telemetry. This is the threshold and sensitivity should be set to half as sensitive for safety. For example, if device begins sensing patient's underlying beats at 8 mV, sensing should be set at 4 mV for safety. Undersensing occurs when

pacemaker is not seeing intrinsic cardiac signals. This produces "over-pacing" as it is not accounting for intrinsic beats. This inappropriate pacing can occur on a T wave, causing VT/VF. If undersensing (Fig. 18.10) is suspected, turn sensitivity dial to a lower mV setting to make more sensitive. It is a good memory tool to think of sensitivity setting like a fence. The higher the fence (10 mV), the less can be seen over it. The lower the fence (0.4 mV), the more can be seen.

Oversensing is the opposite with the device seeing too many signals and inhibiting the pace impulse. These signals may be due to environmental factors such as electrocautery. Oversensing leads to underpacing when it should be pacing (Fig. 18.11). If oversensing is suspected, turn dial to a higher mV setting on pacing box to make device less sensitive. For example, if sensing is set at 1 mV and oversensing is seen on telemetry, turn knob to 4 mV to see if this fixes the problem.

Fusion complexes are another finding seen on telemetry. These are a combination between a normal conducted beat and a paced beat with a pacing spike and QRS similar to intrinsic morphology.

Keys to Success, Perils, Pitfalls

For most patients with any type of temporary pacemaker in place, the cardiology team will be involved in management. They will make determinations about how long the patient will need a temporary device and when permanent device is needed. Temporary wires are usually only used for 3–5 days before placing permanent device is discussed as infection risk goes up the longer the catheter is in place. Many physicians consider starting prophylactic antibiotics if temporary wire must be kept in place for more than 7 days or if the femoral route is used. Temporary permanent devices can be in place for weeks, but extreme care must be taken to clean and dress the site of externalization to decrease infection risk. Epicardial wires stay in place less than 7 days due to risk of lead failure over time.

CPT Coding

- CPT 93953: Temporary transcutaneous pacing

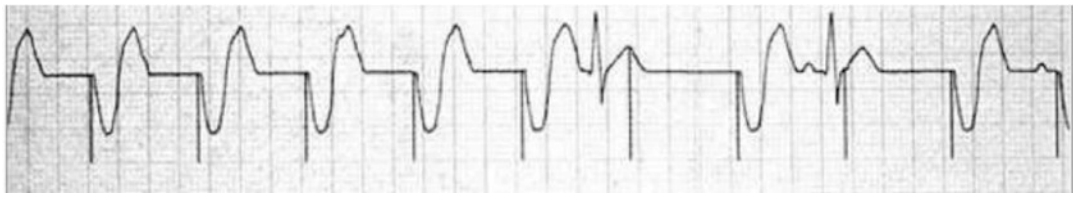

Fig. 18.10 Example of undersensing with pacing spikes marching through without being affected by intrinsic cardiac rhythm

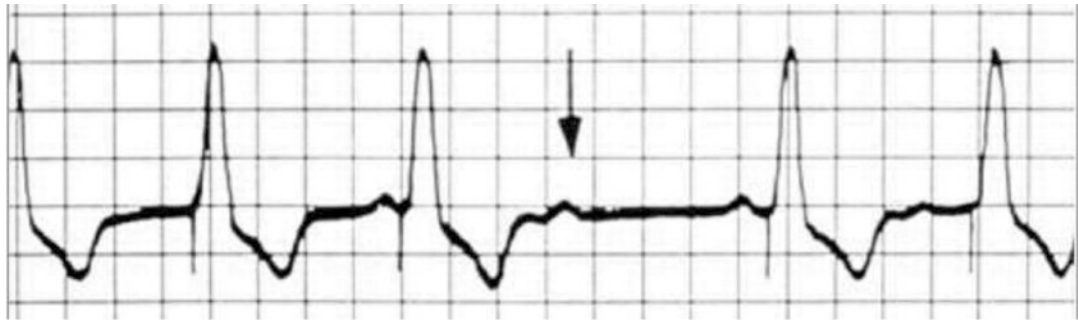

Fig. 18.11 Example of oversensing where device sees the P wave, interprets it as a ventricular signal, and withholds pacing

- CPT 33210: Insertion or replacement of temporary transvenous single-chamber cardiac electrode or pacemaker catheter
- CPT 33211: Insertion or replacement of temporary transvenous dual-chamber pacing electrodes

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19 Intra-aortic Balloon Pump Counterpulsation

Kyle Briggs, Gabriel Najarro, and Omer Mirza

Introduction

The intra-aortic balloon pump (IABP) is a mechanical circulatory support device which may be placed into the descending thoracic aorta in order to support a patient's hemodynamics. The goals of intra-aortic counterpulsation are to improve coronary perfusion, reduce afterload, and thus decrease myocardial demand. Augmentation of coronary perfusion occurs during diastole, when the IABP inflates and provides retrograde flow in the ascending aorta. During systole, the IABP rapidly deflates, resulting in reduced afterload and a reduction in systolic blood pressure, which promotes forward flow. This reduction in work performed by the left ventricle results in a lower oxygen demand [1]. The IABP has been widely used since its conception in the 1960s and is the most commonly used mechanical support device for critically ill patients [2]. While it may be placed surgically, it is most commonly placed percutaneously under fluoroscopic guidance via the femoral artery.

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Indications

- Cardiogenic shock
- Acute myocardial infarction (AMI)
- High-risk percutaneous coronary intervention
- Severe mitral regurgitation secondary to AMI
- Weaning from cardiopulmonary bypass
- End-stage cardiomyopathy/bridge to transplantation or LVAD

Contraindications (Table 19.1)

Risks/Benefits

The IABP is placed in order to provide enhanced coronary perfusion and to reduce the workload of the heart. This is performed by placing an elongated balloon into the femoral artery and advancing to the aorta. Once in place, the balloon

Table 19.1 Absolute and relative contraindications to IABP support

Absolute	Relative
Aortic aneurysm Aortic dissection (thoracic or abdominal) Severe aortic insufficiency Severe calcified aortic-iliac disease Severe peripheral vascular disease	Contraindication to intravenous anticoagulation Moderate aortic insufficiency Moderate peripheral vascular disease Aortic or iliofemoral bypass grafts Sustained tachyarrhythmias (HR >160)

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will inflate during diastole, sending blood into the coronary arteries, and deflate during systole, which will reduce the pressure the heart must overcome in order to pump blood forward.

Although an invasive procedure, IABP insertion is commonly conducted in compromised cardiac condition despite maximal pharmacologic therapy. One of the most common procedural risks is bleeding, especially at the site of insertion. Other risks include infection, limb ischemia, thrombocytopenia, thrombus formation with subsequent thromboembolic events, aortic dissection/rupture, intra-abdominal malperfusion (e.g., renal artery compromise with incorrect sizing or distal placement), and decreased or even loss of blood flow to the limb where the balloon will be placed.

In addition to these risks, informed consent should also include patient understanding of post-procedural care. Namely, IABP placement will necessitate supine positioning for duration of device use (unless the IABP will be placed to the axillary position). Prevention of kinking or retraction of the catheter by limiting motion is paramount.

Preparation

Personnel and Patient Preparation

Preparation for the patient about to receive an IABP should include planning for procedure location, arterial access selection, patient assessment, and preparation for the procedure itself.

Procedure Location

Placement of the IABP is preferably performed with the assistance of fluoroscopy if at all possible. Approximately two-thirds of IABP placements are performed in cardiac catheterization laboratories, and about one-quarter placed in the operating room. The remaining fraction are placed bedside in the ICU [3]. If fluoroscopic-assisted guidance is not possible, an X-ray technician should be present at the bedside to perform chest X-rays for placement confirmation.

Arterial Access Selection

The two major access points for IABP insertion are the axillary and femoral arteries. The former is not only less common, but more technically challenging as it will require a surgical cutdown and graft creation for insertion. As this is beyond the scope of this review, the following description will focus on femoral insertion [4].

Patient Assessment

A complete vascular physical examination should be performed prior to placement. The assessment should include auscultation of bilateral femoral arteries and lower abdomen. Assessment of pulses should be performed at the femoral, dorsalis pedis (DP), and posterior tibial (PT) sites, and the findings should be documented to compare with future assessments. The femoral artery with the best pulse or the extremity with least degree of distal peripheral vascular disease (as estimated from caliber of pulse or sonographic visualization) should be selected in order to minimize the risks of vascular complications [5]. The sizing of the IABP is also of considerable importance, as previously mentioned risks including compromised intra-abdominal vasculature may result from inappropriate sizing. A variety of different balloon sizes are available [6] (Fig. 19.1). Table 19.2 lists the more common balloon sizing schemes, although it should be noted that sizing characteristics of IABP can vary by manufacturer.

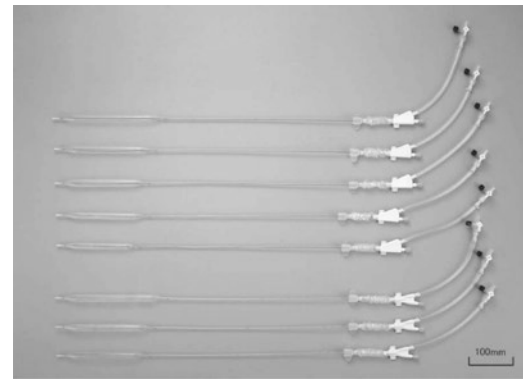

Fig. 19.1 IABP catheter size examples from top to bottom. 9Fr/40 cc, 9Fr/35 cc, 9Fr/30 cc, 9Fr/25 cc, 9Fr/20 cc, 8Fr/40 cc, 8Fr/35 cc, 8Fr/30 cc

Table 19.2 Balloon dimensions and patient height

Balloon size	Diameter	Inflated balloon length	Patient height
34 cc	7.5 Fr	16 mm 14.7 cm	147– 162 cm
40 cc	7.5 Fr	16 mm	162– 182 cm
50 cc	8.0 Fr	17.4 mm	>182 cm

Prior to insertion, transthoracic echocardiography should be performed to evaluate for the presence of severe aortic regurgitation, a contraindication for placement [4]. During intraoperative IABP placement, transesophageal echocardiography may also be utilized to evaluate adequate positioning as well [5].

Patient Preparation

The patient should be placed supine with the lower extremity utilized extended and laterally rotated. An anti-infective solution (e.g., chlorhexidine) should be applied liberally to procedural area, and the patient should then be draped in a sterile fashion with a repeat of anti-infective solution at insertion site once draping is in place to maintain sterility.

Equipment

(a) IABP kit with appropriate balloon size (Figs. 19.1 and 19.2)
(b) IABP console
(c) Face mask with eye shield, sterile gloves and gown
(d) Sterile drape
(e) Chlorhexidine 0.5% with alcohol 70% (or other anti-infective solution)
(f) Suture material
(g) Large dressing pack
(h) Pressure bag with 500 ml 0.9% sodium chloride
(i) Extension tubing for transducer
(j) Transducer cable for IABP
(k) ECG cable for IABP

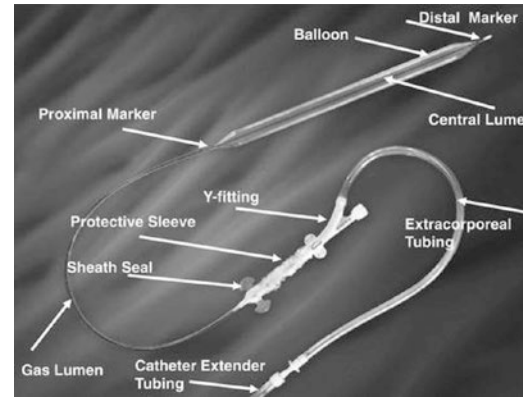

Fig. 19.2 Contents of the intra-aortic balloon pump kit

Procedure

Placement

The insertion of the IABP follows the steps below:

1. After shaving and cleaning the area of insertion, the patient will be draped and undergo anti-infective preparations as detailed above.
2. Identify the common femoral artery at the intersection with the inguinal ligament (Fig. 19.3). The inguinal fold is an approximation of the inguinal ligament, although body habitus may distort anatomy. Ultrasound guidance can assist in proper insertion (i.e., above femoral bifurcation and avoiding anterior calcification or significant occlusive disease).
3. After superficial injection of local anesthetic, an introducer or micropuncture needle is inserted into the common femoral artery above the femoral bifurcation and below the inguinal ligament. This will reduce the risk of pseudoaneurysm formation, limb ischemia, and bleeding complications by avoiding the inferior epigastric artery and subsequent risk of retroperitoneal bleed.
4. Once arterial access is gained, Seldinger technique is utilized with serial dilators exchang-

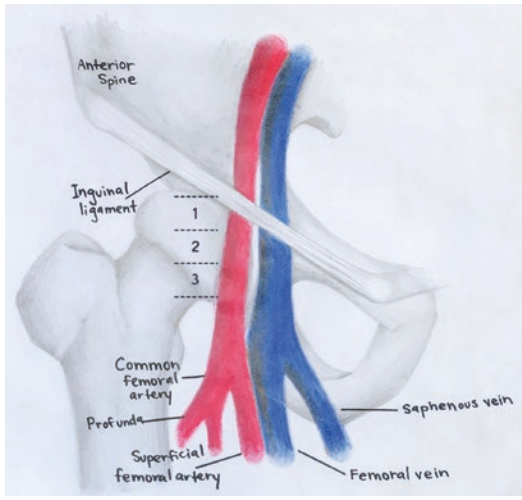

Fig. 19.3 Optimal access for IABP placement is superior to the femoral artery bifurcation in the common femoral artery near the middle third of femoral head and inferior to the inguinal ligament. Shown here as right femoral artery. (Design created by Elizabeth Duffy)

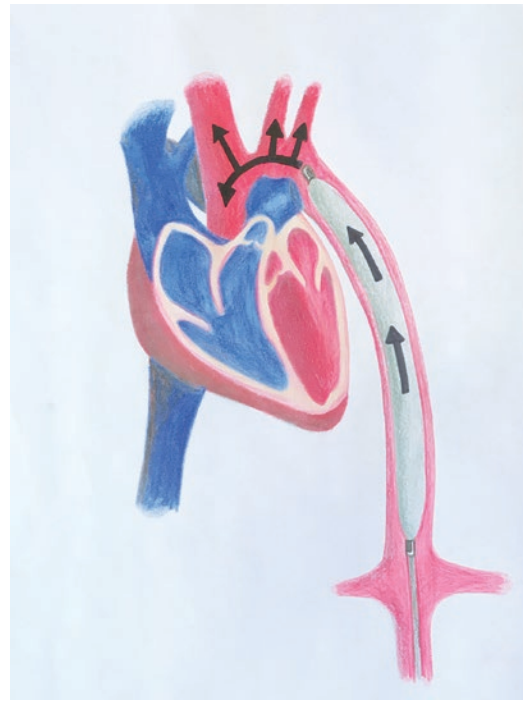

Fig. 19.4 IABP positioning in the proximal descending aorta during cardiac diastole. (Design created by Elizabeth Duffy)

ing for appropriate sheath size (Table 19.2) over 0.035″ J-tipped guidewire.

5. IABP is advanced over an 0.018″ guidewire until distal marker is either 2 cm distal to the origin of left subclavian artery or 1–2 cm proximal to bifurcation of bronchial carina. This is ideally done under fluoroscopy for direct visual guidance. If fluoroscopy is unavailable, estimate the amount of advancement necessary by measuring from common femoral artery to umbilicus, to the manubriosternal junction. It is essential that the IABP is placed in appropriate position in order to provide optimal hemodynamic effects during diastole and systole, as well as avoiding obstruction of the subclavian artery, celiac trunk, or renal arteries (Figs. 19.4 and 19.5).
6. Once the balloon is in adequate position, the guidewire is removed and the central lumen of the balloon is flushed. The IABP is connected to the console and counterpulsation is initiated. Identification of balloon placement with chest radiography should occur as soon as possible following placement to ensure positioning. Proper positioning can be ascertained by noting that the IABP tip is located below the level of the aortic arch at the level between the second and third intercostal spaces and at or above the level of the carina (Fig. 19.6). TEE may also be used in the critical care setting [3].
7. Once counterpulsation has been initiated, pressure tracings should be evaluated for timing while on a 1:2 setting in which the balloon inflates and deflates with every other heartbeat (Fig. 19.7). The IABP console should be checked to ensure proper functioning and that all waveforms and pressures are satisfactory (Fig. 19.8). Once timing and positioning are satisfactory, the balloon is set to run continuously at the desired frequency, commonly at 1:1 triggering to start. It should be noted that any adjustments in positioning while troubleshooting should occur while the balloon is placed in standby mode in order to avoid injury to the aorta.
8. The IABP line is secured into place with sutures and covered with a protective dressing. A repeat vascular exam should be per-

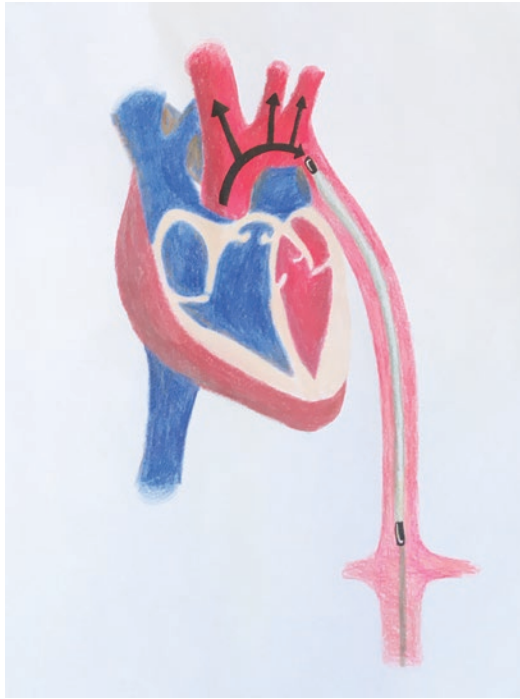

Fig. 19.5 IABP positioning in the proximal descending aorta during cardiac systole. (Design created by Elizabeth Duffy)

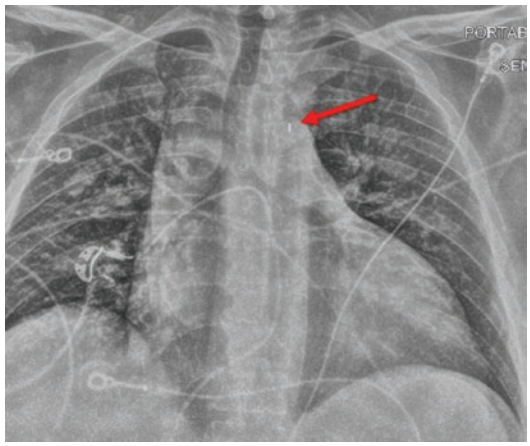

Fig. 19.6 An anterior-posterior chest radiograph demonstrates a properly positioned intra-aortic balloon pump tip (red arrow) sitting inferior to the left subclavian artery and above the level of the carina

formed to ensure that distal circulation remains intact to bilateral upper and lower extremities. Pulses should be regularly evaluated in bilateral dorsalis pedis, posterior tibial, and left radial sites. Daily radiographs should be performed to ensure that balloon positioning remains appropriate. Patients with an IABP placed into the femoral artery are to remain on bedrest, and the leg with site of insertion should be immobilized [7].

Post-Procedural Care

1. Triggering
   Optimal timing of IABP inflation and deflation occurs with the closing and opening of the aortic valve, respectively. Modern devices utilize fiber-optic technology which are able to match the inflation of the balloon to within 12 milliseconds of aortic valve closure [8]. The triggering of balloon may be accomplished by evaluations of ECG, pressure, pacemaker spikes, or asynchronous methods (Table 19.3).
2. Timing
   Suboptimal timing of inflation can have significant hemodynamic consequences. The four main types of improper timing are: early inflation, late inflation, early deflation, and late deflation.
   - *Early inflation* occurs when the balloon inflates before aortic valve closure. It may be detected when the diastolic augmentation is noted prior to dicrotic notch. This results in increased ventricular afterload, premature closure of aortic valve, reduced cardiac output, and increased myocardial oxygen demand (Fig. 19.9).
   - *Late inflation* is a delay in balloon inflation, resulting in inflation late in the diastolic cycle. It may be seen on waveform as an inflation after the dicrotic notch with the absence of a sharp V shape as is seen with optimal timing. This can also lead to suboptimal diastolic augmentation and results in suboptimal coronary artery perfusion (Fig. 19.9).
   - *Early deflation* is found when the balloon deflates before the end of diastole. It can be detected when there is suboptimal diastolic augmentation, a sharp drop following dia-

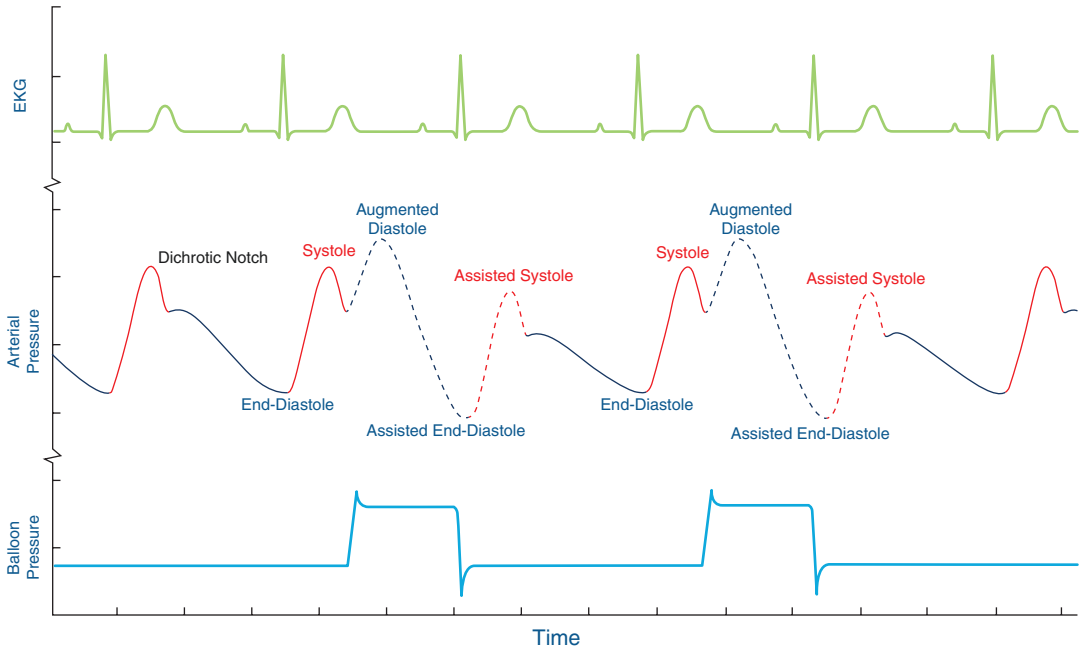

Fig. 19.7 Illustration of IAB counterpulsation with a 1:2 augmentation ratio. (Design created by Gabriel Najarro)

stolic augmentation, and an assisted aortic end diastolic pressure that is equal or less than the unassisted end aortic diastolic pressure. This results in suboptimal coronary perfusion and suboptimal afterload reduction (Fig. 19.10).

– *Late deflation* is a delay in balloon deflation which will result in an inflated balloon during cardiac systole. Waveform interpretation may show an assisted aortic end diastolic pressure that is equal to the unassisted aortic end diastolic pressure and a diastolic augmentation that appears widened. This results in poor afterload reduction, increased ventricular afterload, and increased myocardial oxygen demand (Fig. 19.10).

3. Anticoagulation
   Continual counterpulsation with the IABP in a 1:1 ratio results in a reduced risk of thrombus formation; therefore, there are no current standards to provide anticoagulation in this setting. If the counterpulsation is reduced, then the risk for thrombus increases and anticoagulation should be provided. This is most commonly accomplished with intravenous heparin infusion. Animal studies have shown thrombus formation to occur in as little as 20 minutes in the absence of counterpulsation [8]; thus, the IABP should never be placed in standby mode unless it is being removed.
4. Daily Monitoring
   Daily monitoring should consist of complete assessments of distal pulses, notable to include DP and PT pulses of the leg with IABP in place, as well as assessment of left radial pulse. A chest radiograph should be performed daily to assess for balloon migration. Insertion sites should be monitored frequently for bleeding or hematoma formation.

Removal

Removal of the IABP is ideally performed once hemodynamic stability has been achieved and maintained and the reason for IABP insertion has been corrected. Hemodynamic stability without counterpulsation can be estimated by performing weaning trials in which the IABP is

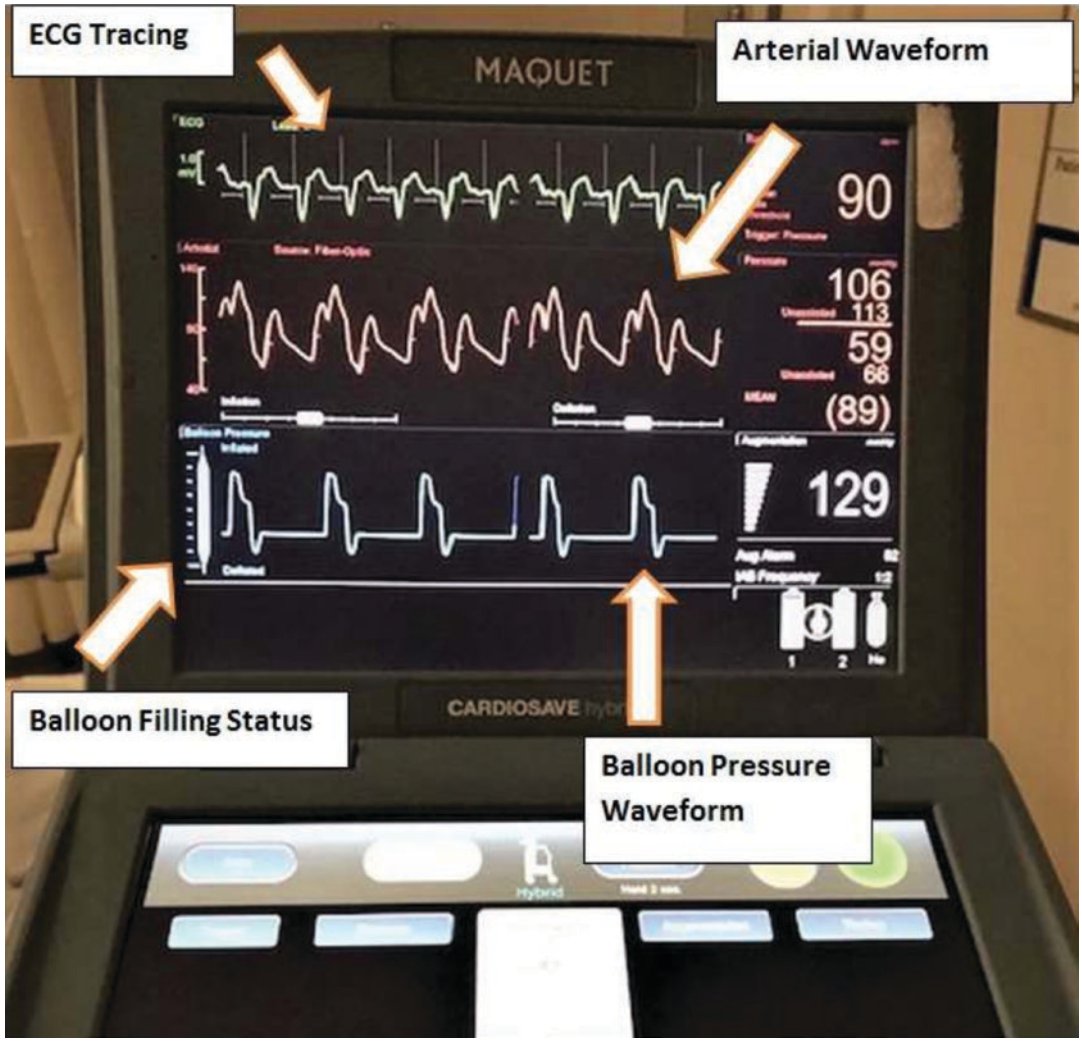

Fig. 19.8 Example of IABP console and waveform locations

set to 1:2 or 1:3 cycle rates. During this time, monitoring is ongoing to assess the patient's estimated cardiac output, heart rate, symptomatic changes, and other signs which may suggest hypoperfusion. It is important to provide anticoagulation to prevent thrombus anytime that the IABP is not in a 1:1 ratio as thrombus on the balloon surface can occur rapidly [8]. Once the trial is completed, the IABP should be returned to a 1:1 ratio while anticoagulation held until time for removal.

Occasionally, the IABP will need to be removed emergently owing to pump malfunction or complication. A malfunctioning balloon should be removed as quickly as possible to minimize the risk of thrombus formation, preferably within 20 minutes [8]. In these settings, weaning trials should not be performed.

Steps to IABP removal include the following:

1. Anticoagulation should be held to allow for easier hemostasis once the IABP is removed. It is ideal to wait until ACT is <180 or aPTT <40 seconds. It is important to maintain the IABP at a 1:1 ratio during this time. During this period, gather a suture removal kit, waste bin, gauze, transparent pressure dressing, gloves, and face mask with eye shield.

Table 19.3 Methods and considerations for various modes of IABP triggering

Trigger	Method	Considerations
ECG	Deflation at peak of R wave Inflation triggered at middle of T wave	Less reliable during arrhythmias or poor ECG quality
Pressure	Balloon inflation and deflation triggered by arterial pressure waveform	Usually accomplished via fiber-optics May be transduced via sheath sideport
Pacemaker	Balloon inflation and deflation set to correlate with ventricular spike	Useful for ventricular and atrioventricular pacing Patient should have a 100% paced rhythm
Asynchronous (internal trigger)	Usually set to augment at a rate of 80 beats/min	Only used in situations of no cardiac output/ cardiac arrest

2. Identify the femoral pulse 2–3 cm proximal to IABP insertion site and mark this area for pressure to be held once IABP has been removed. Assess the distal pulses of lower extremities in both DP and PT areas either by palpation or Doppler. Prepare the patient by explaining the steps to IABP removal and answer any questions if they have not been addressed. Consider analgesia, as appropriate for the situation. Don gloves and mask and carefully remove adhesive dressing and sutures.
3. Place IABP system in standby mode. This will allow the balloon to deflate. A three-way stopcock may be attached and air manually removed via a large syringe to ensure that gas has adequately been removed from the system.
4. Retract the balloon through the sheath until resistance is felt once the balloon encounters the sheath. Once this is performed, remove the balloon and sheath as one until both are fully removed with one hand while the other hand

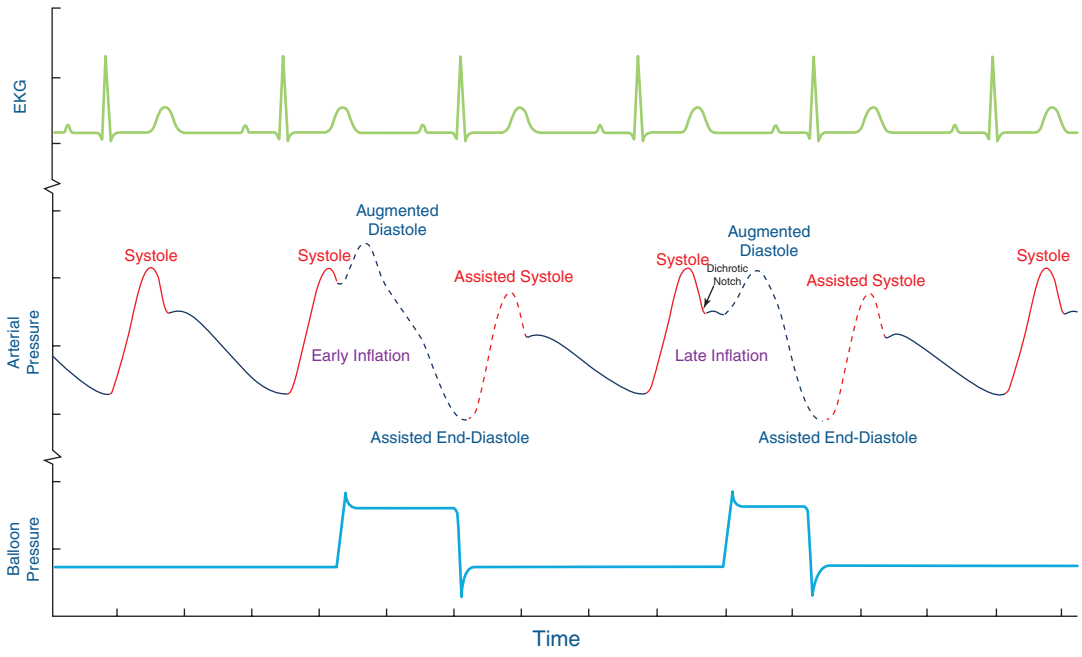

Fig. 19.9 Illustration of IAB counterpulsation with a 1:2 augmentation ratio with abnormal inflation timing. (Design created by Gabriel Najarro)

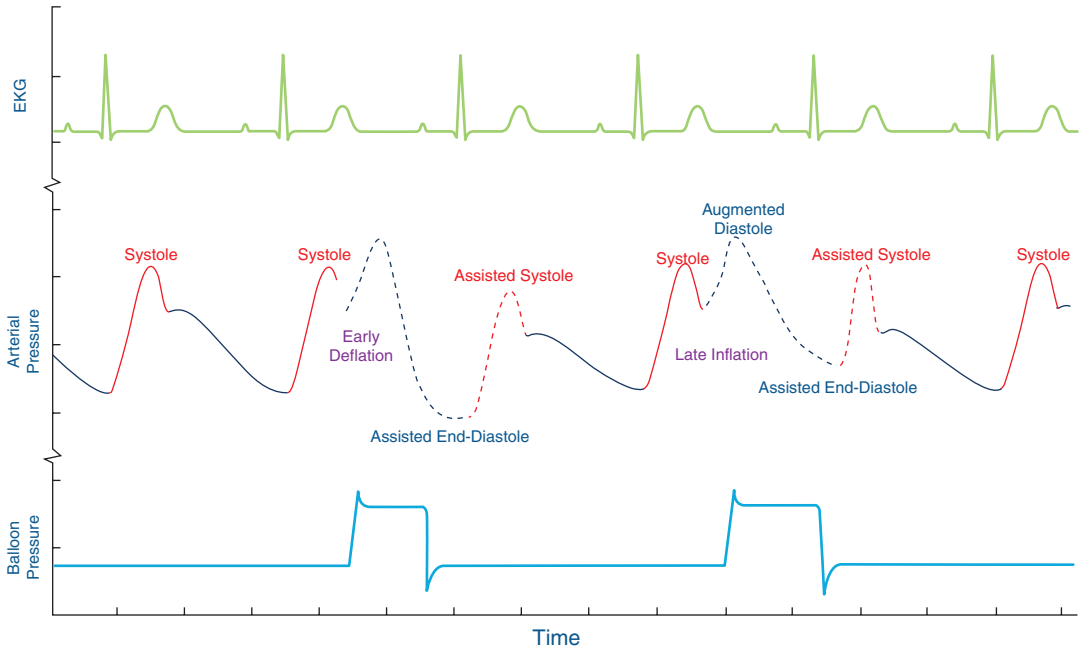

Fig. 19.10 Illustration of IAB counterpulsation with a 1:2 augmentation ratio with abnormal deflation timing. (Design created by Gabriel Najarro)

is at the site proximal to insertion and previously identified as spot to hold direct pressure. After the IABP and sheath have been fully removed, place it in an appropriate biohazard waste bin and allow for 1–2 seconds of bleeding to allow for any thrombi to be expelled.

5. Apply and maintain direct pressure to the site of femoral artery proximal to IABP insertion previously identified. Press hard and ensure cessation of bleeding from the femoral access site, with direct visualization of puncture site throughout the entire process. Pressure should be held for a minimum of 30 minutes, monitoring for hemostasis, with attention to search for hematoma formation at the site of IABP removal.
6. Upon completion, apply a transparent pressure dressing, and maintain the leg in a straight position with bedrest for 4–6 hours. Continue to assess distal pulses to ensure that they remain present.

Complications

Complications may be either from vascular or non-vascular events, with bleeding and arterial trauma being the most common. Major complications are typically defined as severe bleeding, major limb ischemia, balloon leak, or in-hospital mortality. In registry data, less than 3% of patients typically suffer major complications. Risk factors for major complications include peripheral vascular disease, female gender, BSA < 1.65 m^2, and age ≥ 75 years [9, 10]. Inotropic medications should be considered on a case-by-case basis for support of hemodynamics if a significant period of troubleshooting is expected.

Vascular Events

Vascular events typically include limb ischemia, hematoma, and hemorrhage [11] (Table 19.4).

Table 19.4 Major complications and unadjusted mortality rates for US and non-US institutions

	Total $n = 22,663$	US institutions $n = 19,636$	Non-US institutions $n = 3027$	P value
All cause in-hospital mortality, n (%)	4819(21.3)	3951(20.1)	868(28.7)	<0.001
Mortality: balloon in place, n (%)	2669(11.8)	2125(10.8)	544(18.0)	<0.001
Overall major IABP-related complications				
IABP-related mortality *n* (%)	12(0.053)	10(0.051)	2(0.066)	0.736
Major limb ischemia, *n* (%)	194(0.9)	169(0.9)	25(0.8)	0.847
Severe bleeding, *n* (%)	196(0.9)	173(0.9)	23(0.8)	0.790
Balloon failure/leak, *n* (%)	827(3.6)	704(3.6)	123(4.1)	0.341

Based on data from Ref. [10]

Limb Ischemia

Risk factors for limb ischemia include the presence and severity of peripheral vascular disease, catheter size, smoking history, and distal site of insertion – as the distal femoral branches are often not large enough to accommodate for IABP insertion. If limb ischemia is encountered, then the IABP must be removed and pressure held until hemostasis is achieved. If ischemia does not resolve after removal of IABP and control of hemostasis, then evaluation by a vascular surgical specialist is warranted.

Bleeding

Bleeding due to arterial trauma is among the more common complications of IABP placement and removal. This may be seen as frank blood loss or hematoma formation and is treated with manual pressure at the site of blood loss with attention to control bleeding from the more proximal aspect of arterial flow. Occasionally supportive care with blood transfusion is required. Uncontrolled hemorrhage that is not able to be managed with manual pressure may indicate the presence of substantial injuries, such as arterial laceration, and warrants evaluation by a vascular surgical specialist.

Pseudoaneurysm

Pseudoaneurysm is a rare but potential complication most commonly encountered following IABP removal. Evaluation with vascular ultrasound can be used to better characterize such injuries. Surgical intervention is often required.

Thrombocytopenia

Thrombocytopenia has been observed in retrospective studies with an incidence as high as 50% of patients with IABP [12]. The hypothesized mechanism is likely multifactorial and related to platelet adhesion to the balloon surface, platelet activation in response to endothelial damage, routine systemic heparinization, and/ or critical illness. Platelet counts should be monitored daily to assess for bleeding risk [13, 14].

Balloon Rupture

Balloon rupture should be considered if blood is noted in the gas driveline tubing or if there is a loss of diastolic augmentation. The patient should be positioned with head down, as the balloon is filled with helium and could potentially cause a stroke, although this is less likely as helium rapidly dissolves into the bloodstream and has a low viscosity. The ruptured balloon will be unable to function and will rapidly become a nidus for thrombus formation. The IABP should be removed as soon as possible.

Balloon Entrapment

Balloon entrapment may occur in the setting of balloon rupture when thrombus attaches to the

inside of the balloon and is therefore unable to deflate. This will be encountered as resistance when attempting to remove the IABP. If this is suspected, the patient should be taken emergently to fluoroscopy to evaluate the position of the balloon. If entrapment is found, surgical removal is necessary.

Keys to Success, Perils, and Pitfalls

Ultrasound-guided access can aid to prevent multiple complications. Ultrasonography can be useful to identify anterior wall calcification and/or significant occlusive atherosclerosis that may predispose to limb ischemia. Ultrasonography is also useful in delineating the femoral bifurcation, which will assist in placement site selection and prevent pseudoaneurysm formation.

Aortoiliac angiography can be utilized to assess aortoiliac anatomy, namely, occlusive disease or aneurysmal formation. As the aortoiliac anatomy can be obscured during ultrasonography, a limited angiogram can be conducted in the cath lab. Should this be pursued, consider an initial insertion of a 5F femoral sheath (rather than larger bore sheaths necessary for IABP) and advancing a 5F multi-hole pigtail catheter to conduct angiography. The smaller sheath size can allow manual compression to close arteriotomy should anatomy not be amenable to IABP insertion.

As minimal movements can cause inappropriate positioning, fluoroscopic documentation of correct placement should occur after final suturing. A chest X-ray should be taken after transportation to the ICU to ensure continued proper positioning and should be documented.

Removal of IABP may be made easier by removing excess air from tubing by attaching a three-way stopcock and aspirating via a large syringe to ensure that gas has adequately been removed from the system. An assistant may be required to maintain negative pressure. This may be especially helpful in situations where the balloon needs to be removed but sheath will remain in place.

- If the patient has a cardiac arrest, switch the pump to pressure triggering and reduce augmentation to 50%.
- In the setting of significant tachycardia or tachyarrhythmias, a timing ratio of 1:2 may allow for more optimal hemodynamic effects.
- Leg immobilization is an important component of care to prevent complications. This will prevent obstruction or kinking at the femoral access site, as such a leg or knee immobilizer should be utilized to prevent unintentional hip flexion [7].

CPT Coding

- CPT 33967: Insertion of intra-aortic balloon assist device, percutaneous
- CPT 33970: Insertion of intra-aortic balloon assist device through the femoral artery, open approach
- CPT 33968: Removal of intra-aortic balloon assist device, percutaneous

Summary

The intra-aortic balloon pump is a temporary mechanical support device which is commonly used in the intensive care setting. It is most commonly placed percutaneously using Seldinger technique and has been utilized for many years in order to augment coronary perfusion, reduce afterload, and decrease myocardial oxygen demand.

Additional Resources

- An introduction to Intra aortic balloon pumping [15]
- Timing and triggering of the Intra-aortic Balloon Pump (IABP) [16]
- Intra Aortic Balloon Pump by Ray Raper at SMACCGold [17]
- Cardiogenic Shock and Intra-aortic Balloon Pump by Dr. Cal Shipley, M.D. [18]

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Resuscitative Thoracotomy

20

Jessica Jurkovich

Introduction

The resuscitative thoracotomy is an emergency procedure performed most often following blunt or penetrating trauma and most commonly in the emergency department (ED) setting, hence the alternative name "ED thoracotomy" (EDT). A resuscitative thoracotomy can also be performed in the operating room or even the intensive care unit. The EDT is essentially a rapid opening of the left thoracic cavity to allow the provider access to the pericardium, the heart, the thoracic aorta, and the lung and thereby "resuscitate" a patient in cardiac arrest. Since its introduction nearly 50 years ago, emergency department thoracotomy (EDT) has remained among the most polarizing and controversial procedures that physicians perform. It is a morbid procedure that has limited indications; therefore, institutional protocols typically guide its use and application. These indications include specific mechanism of injury, the presence or absence of physiological signs of life (pupillary response, carotid pulse, measurable blood pressure, cardiac rhythm), and timing of cardiac arrest [6]. Given EDT's narrow indications, often those performing or assisting with the procedure have limited experience. The role of this chapter is to guide the advanced practice provider in understanding the appropriate indications for a resuscitative thoracotomy, provide them with information to assist the surgeon, and provide a guide to avoid common pitfalls or complications of this potentially life-saving technique.

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Indications

Review

The most common indication for an EDT is for patients who have sustained penetrating trauma to the chest and are in severe shock or near death, but exhibit some signs of life [8]. Of this population, those who benefit most have an established secure airway, short transport times, and a measurable blood pressure [2]. Many centers have broadened their indications for an EDT to include both blunt injury and penetrating torso injury, despite lower survival rates due to frequent multiorgan injury patterns in these mechanisms. Thus, there is some variability in institutional and organizational guidelines on the exact indications for an EDT. For example, the Advanced Trauma Life Support (ATLS) Course [1] notes that the EDT is solely indicated in the penetrating, not blunt, trauma patient who is pulseless but has myocardial electrical activity.

The Eastern Association for the Surgery of Trauma (EAST) notes that when considering a

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resuscitative ED thoracotomy, clinicians must balance limited salvage rates against considerable potential risks including exposure of personnel to blood-borne pathogens, a highly morbid procedure, and medical expenses [5]. EAST advocates a selective approach to the performance of EDT based on the presence or absence of several predictors of survival. Like the ATLS course, EAST guidelines conclude that patients who present pulseless but with signs of life after penetrating thoracic injury should undergo EDT. They are less strong in their recommendations ("conditionally recommend") for the following patients: those who present pulseless with absent signs of life after penetrating thoracic injury; those who present pulseless but with signs of life after penetrating extra-thoracic injury; those who present pulseless with absent signs of life after penetrating extra-thoracic injury; and patients who present pulseless but with signs of life after blunt injury. Importantly, they do not recommend EDT for patients who present pulseless with absent signs of life after blunt injury [7].

The Western Trauma Association has a slightly different and more liberal approach to the indication for EDT, described in a treatment algorithm approach that begins with a trauma patient with no signs of life undergoing cardiopulmonary resuscitation (CPR) [2]. In a blunt trauma mechanism, if CPR has been performed for less than 10 minutes, they recommend resuscitative thoracotomy. In a penetrating mechanism, CPR performed for less than 15 minutes is an indication for resuscitative thoracotomy.

Definitions

Despite variations in the indications for EDT, most authorities divide their suggestions based on the presence of signs of life, mechanism of injury, and location of injury. For these purposes the definitions are noted below:

Signs of Life: Signs of life are generally considered to include spontaneous respiratory effort, palpable pulse or measurable blood pressure, electrical cardiac activity, and pupillary activity. Somewhat controversial is what constitutes electrical cardiac activity, ranging from any cardiac activity to an identifiable rhythm. Asystole is no cardiac activity.

Mechanism of Injury: This is divided into blunt and penetrating, and penetrating further divided into gunshot and stab wounds.

Location of Injury: This is divided into thoracic, non-thoracic torso (abdomen, back, and flank), extremities, head, and neck.

Specific Indications

Based on the above definitions, specific indications are reviewed below.

Penetrating Chest Trauma This is the mechanism and location of injury most likely to benefit from an EDT, and particularly if stab is the mechanism of injury. As such, this is often the most "liberal" of indications for performing a resuscitative thoracotomy. Findings that are most compatible with salvage are pericardial tamponade, major injury from the lung, or a cardiac wound. Maneuvers that can occur are opening of the pericardium to evacuate a tamponade, repair of a cardiac wound, and resection or suture ligation of a bleeding lung injury.

Blunt Chest Trauma This mechanism and location of injury is difficult to discern, as blunt force injury typically involves the entire body. However, if direct blunt force thoracic injury is suspected, the patient is in extremis, and/or cardiac arrest has occurred in the emergency department or shortly (less that 10 min) prior to arrival, EDT can be indicated. Findings that are most compatible with survival would be blunt rupture of a cardiac atria, which will cause tamponade, and which can readily be clamped and repaired. Blunt rupture of a cardiac ventricle is, however, unlikely to survive. Additionally, cross-clamping of the intra-thoracic aorta is often also performed in an effort to improve coronary and cerebral flow and to decrease or stop any bleeding below the diaphragm in blunt injuries.

Penetrating Non-thoracic Trauma The use of retrograde endovascular balloon occlusion of the aorta (REBOA) has become an alternative to ED thoracotomy in this setting. However, if EDT is performed, the goal is to cross-clamp the thoracic aorta to decrease or stop hemorrhage below the diaphragm, and allow time to transport to the operating room (OR) for an exploratory laparotomy and definitive hemorrhage control. In general, this indication would be in a patient with profound shock (systolic blood pressure (SBP) < 70 mm Hg), with clear signs of life, who has lost consciousness due to a truncal wound [3].

Blunt Non-thoracic Trauma The use of REBOA has become an alternative to ED thoracotomy in this setting. The goal of EDT, as in penetrating non-thoracic trauma, is to cross-clamp the thoracic aortic to decrease or stop hemorrhage below the diaphragm, and allow time to transport to the OR for an exploratory laparotomy and definitive hemorrhage control. Similarly there is also a role for interventional radiology for angio-embolization of retroperitoneal hemorrhage (renal), hepatic, spleen, or pelvic injuries associated with bleeding. In general, the indication for EDT has become increasingly rare as studies have continued to show dismal survival rates in patient presenting with no blood pressure and minimal signs of life [7].

Contraindications

Absolute Contraindications

- Patient with no signs of life in the field from either penetrating or blunt trauma.
  - Timing is debated but the most liberal of recommendations suggest that EDT is futile and not indicated if there is greater than 10 minutes of CPR in blunt trauma and greater than 15 minutes of CPR in penetrating trauma with no signs of life [4].
- Known do-not-resuscitate status of a patient.

Relative Contraindications

- Absence of cardiac wall motion
- Lack of resources, surgeon access
- Inability to safely perform the procedure

Risks and Benefits

Risks

An emergency thoracotomy is often performed as a life-saving intervention, usually after the patient has clinically arrested. This can be a stressful situation where little is known regarding the patient's past medical history, including active infections, medications, or end-of-life wishes. The priority in any emergency should be to do no harm, both to the patient and the care providers. Thus, proper personnel protective clothing and equipment is crucial. Additionally, to minimize the risk of exposure to blood-borne pathogens, there must be a limit on the number of people within or near the surgical field, and clear communication regarding the use and disposal of sharps is essential [8]. For the patient, risks include: rib fractures, sternal fracture, hemorrhage, cardiac ventricular wall injury, gut and limb ischemia from aortic cross-clamping, aortic injury, lung injury, diaphragm injury, and cardiac and neurologic infarction due to embolic events, and of course death, or survival with a devastating anoxic brain injury. If in the rare situation informed consent can be obtained from family at bedside, communication of these risks is imperative.

Benefits

Benefits of performing a resuscitative thoracotomy are the ability to potentially relieve reversible etiologies, thereby saving a life. Overall survival rates for resuscitative thoracotomy vary from less than 1% to 40%, highest for penetrat-

ing isolated cardiac stab wounds with tamponade, and lowest for blunt torso trauma [6]. The Eastern Association for the Surgery of Trauma (EAST) Guidelines review reports that patients presenting pulseless after penetrating thoracic injury had the most favorable EDT outcomes with survival rates of 8–21% (with and without signs of life) and neurologically intact survival of 4–12%. Survival after EDT in pulseless blunt injury patients was 5%, and if signs of life were absent, survival was a dismal 0.7% (7 out of 995 pooled reports) [7].

Preparation

Equipment

- Personal protective equipment: Gloves, mask, eye protection, sterile gloves, gowns.
- Patient prep: Often Betadine or chlorhexidine, but never a formal 10 min wash or 3 min dry time. The fastest prep times (1 min) are with alcohol-containing iodophor or chlorhexidine gluconate (CHG).
- Good lighting and well-functioning suction are essential.
- Two chest tubes (34–36 Fr).
- Rapid infuser for blood/fluids as indicated.
- Well-functioning IV access: Central access with a Cordis, large bore IVs.
- Paddles for internal defibrillation.
- Laparotomy pads.
- *Thoracotomy Tray*. Design and construction of a "thoracotomy tray" is essential trauma hospital equipment. Typically, multiple surgeons are involved in designing the tray that will be used by all providers. Standard sterilized equipment will include:
  - Large scissors (Mayo curved, straight suture cutting) and long- and normal-sized tissue-cutting scissor (Metzenbaum)
  - Scalpels for use with #10 and #20 (large) blades; forceps (tissue handling "DeBakey" forceps and forceps with grasping teeth).
  - Lung-grabbing forceps (Duvall clamp) and lung retracting spatula (Allison spatula)
  - Hemostats (often called "snits" or Kelley clamps)
  - Aortic cross-clamp (DeBakey curved vascular or Cooley-Satinsky angled clamp)
  - Needle driver and suture (3–0 Prolene most commonly used to repair the heart), pledgets (small cotton pads to help prevent the suture from tearing through tenuous tissue)
  - Finochietto rib spreaders (adult and pediatric sizes)
  - Lebsche sternal splitting knife and hammer
- Sutures: It is best to have a variety of suture available including 2–0 and 3–0 silk ties, 2–0 and 3–0 silk on curved non-cutting needles, and 3–0 and 4–0 Prolene on medium and small non-cutting curved needles. Additionally, larger suture (e.g., 0-silk or nylon on a cutting needle) for securing any chest tubes might be required. Definitive closure of the thoracotomy will be performed in the OR if the patient survives, so additional closing instruments and sutures are not needed. If the patient dies, and the chest is to be closed prior to transporting to the morgue, simple running closure of the skin with a large 0-nylon or Prolene cutting needle will suffice.

Personnel

- Team doing the procedure: It would be ideal to have surgical tech from the operating room at bedside to assist in instrumentation if able, but this is rarely the case. More commonly two surgeons will be involved, and the entire thoracotomy tray should be positioned for easy direct access by the operating surgeon.
- Team running resuscitation: A provider leading resuscitation who is not the operating surgeon is best, as is credentialed and experienced airway providers (EM physician, anesthesiologist, respiratory therapist) at the head of the bed to manage the airway and ventilation. Other key team members are the usual trauma team activation members including nursing staff, blood bank personnel, pharmacist, scribes, and "runners."

Medication

- Advanced Cardiac Life Support (ACLS) drugs

Positioning and Preparation

- Supine with left arm extended is not ideal, but is often the position the patient presents in.
- Ideally the patient should be slightly rolled left side up, but this also requires supporting the extended arm on a rest as well.
- The entire thorax, left and right, should be prepped with alcohol-based iodophor or chlorhexidine gluconate. Prep time is essentially seconds, as every second counts in this extreme circumstance. The surgeon/proceduralist may simply ask that Betadine be poured over the chest.
- Draping is usually not accomplished prior to making the incision, but it is ideal to have sterile drapes covering the field surrounding the operation, and this should be done while the thoracotomy is being performed.
- Antibiotics (cephalosporin or MRSA-specific agents) should be administered during the procedure.
- The team leader, based on the situation, directs blood product administration but most often a massive transfusion protocol will be invoked.

Procedure

The most common incision of a resuscitative/ED thoracotomy (EDT) is a left-sided anterolateral thoracotomy. If needed, this can be extended across the mediastinum into the right chest, a so-called clamshell thoracotomy. General anesthesia, narcotics, ketamine, or other sedating or paralyzing agents should not be needed if the patient has arrested. It is important to note that there are only a limited number of actions that can be performed with a resuscitative thoracotomy. These are:

1. Relieving cardiac tamponade
2. Repairing a cardiac wound
3. Controlling intra-thoracic hemorrhage from the lung or great vessels
4. Cross-clamping the aorta to diminish blood loss below the diaphragm
5. Internal cardiac massage and electro-conversion

General Procedural Guidelines Below:

A. *Prep Patient:* The patient is typically on a gurney undergoing CPR. Position the left arm in extension and apply prep, often Betadine, to a large field including the chest wall, neck, and abdomen. Sterile field draping is minimized initially in the interest of saving precious seconds but should proceed in parallel with the procedure.
B. *Incision:* Utilizing 10 blade scalpel, it is a curved incision starting at the sternal edge in the 4–5th intercostal space (females below the breast and males below the pectoralis), curving up into the armpit as the incision extends laterally and follows the natural curve of the ribs. Electro-cautery is not utilized. A sharp incision (knife) with minimal slices (one cut is ideal, but risks injury to the underlying lung) through the skin, subcutaneous tissue down to the intercostal space is made.
C. *Access Thoracic Cavity:* Access between the ribs and into the pleural space can be obtained with a knife or with Mayo scissors, typically starting at the mid-axillary line, pushing the partially opened scissors through intercostal muscles toward midline to the sternum, then reversing up to the axilla allowing a complete view into the thoracic cavity. A retractor (Finochietto) is placed between the ribs and cranked open, somewhat slowly and in stages to prevent unnecessary rib fractures. Note the "blades" or retracting edges of the Finochietto retractor are often not connected during sterilization procedure and need to be appropriately inserted and secured prior to use. They also come in different lengths (sizes) (Fig. 20.1).
D. *Relieve Tamponade:* The key to opening the pericardium in a EDT is to avoid injury to the phrenic nerve, avoid injury to the heart, and allow adequate access to perform as needed

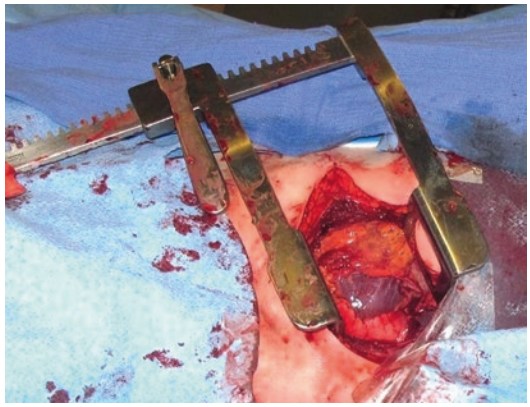

Fig. 20.1 Clamshell thoracotomy. (Courtesy of Richard Mullins, MD)

cardiac repair and/or internal cardiac massage. Pick-ups (forceps) with teeth and tissue scissors (Metzenbaum) are used. An incision parallel to the spine and anterior to the phrenic nerve is made. The phrenic nerve lays one-third up the pericardium from the spine; hence, the incision should be near the middle or top-half of the pericardium with the patient supine. An incision the length of the pericardium is made.

E. *Cardiac Evaluation and Repair:* Pericardial tamponade means a cardiac injury. It must be rapidly identified and repaired. The heart can be lifted out of the pericardial sack to fully explore all sides. Atrial wounds can be clamped first (smaller vascular vessel clamps are ideal) then suture repaired. Cardiac ventricular wall injuries are repaired with Prolene suture, typically on pledgets. On rare occasion, a cardiac ventricular injury can be temporarily closed with a skin-stapler, or occluded with a Foley catheter balloon placed into the wound, the balloon inflated, and pulled taut. If hemorrhage control is obtained, transport to the OR for definitive repair. After temporizing repair and during volume resuscitation, internal cardiac massage (two hands, no thumbs) and cardioversion may be required.

F. *Intra-thoracic, Non-cardiac Hemorrhage*: Evaluate for source and determine if able to control at bedside versus direct transport to operative room (OR). Common sources are the lung, great vessels of the chest (aortic arch, innominate, and subclavian arteries), or intercostal arteries.

   (i) *Pulmonary hemorrhage*: For significant lung injuries, begin by dividing the inferior pulmonary ligament to allow the lung to be fully untethered, followed by the "hilar twist," a rotation of the entire lung 180 degrees. This should control major pulmonary vessel bleeding. Alternatively, suture ligation of the bleeding lung or the use of the linear GIA stapling devise can control lung parenchymal hemorrhage.

   (ii) *Intercostal hemorrhage*: Hold direct pressure and suture ligate.

   (iii) *Great vessel injury*: Hold direct pressure and transfer patient to OR; better exposure, lighting, and additional incisions might be required.

G. *Aortic Cross-Clamping*. The aorta is often cross-clamped just above the diaphragm with a large vascular clamp (DeBakey or Cooley-Satinsky). Exposure of the aorta requires blunt dissection through the posterior parietal pleura and fairly blind placement of the clamp. The esophagus is at risk of injury during this maneuver. Aortic cross-clamping is done to limit blood loss from organs below the diaphragm and to improve blood flow to the brain and coronary arteries.

H. *No Injury Found in the Left Chest.* Typically a resuscitative thoracotomy is begun on the left chest for a mediastinal traversing incision and for the patient in cardiac arrest. A chest tube is inserted in the right chest while the left thoracotomy is underway. If massive blood loss is obtained from the right chest, the left thoracotomy is extended into the right chest by a sternal-traversing incision, often called the "Clamshell thoracotomy."

I. *Clamshell Thoracotomy*.

   (i) *Extend incision*: Extend incision to right nipple either by starting midline and extending to right nipple or approaching

from right 4–5th intercostal, midclavicular line to sternum to meet in the middle.

(ii) *Sternal transection*: There are several approaches to breaking through the sternum, either with Lebsche knife and hammer, Gigli saw, or perhaps available powered sternal saw. Any approach is appropriate.

(iii) *Extend view*: Reposition Finochietto to spread in-between the cut ends of the sternum and divide the fibrofatty tissue between the sternum and anterior pericardium with scissors. This gives an excellent view of the anterior pericardium and access to the right chest (Fig. 20.2).

J. *Internal Cardiac Massage.* In hemorrhagic shock and volume loss, internal direct cardiac compression provides better blood flow to vital organs than external chest wall compression. The best way to perform internal compressions of the heart is with two hands, one flat hand to the posterior surface of the heart and one to the anterior surface, ensuring the heart remains horizontal during the massage as lifting the heart to far vertically can prevent venous return. Do not use one hand and a thumb to perform compression, as the thumb can rupture the heart (Fig. 20.3).

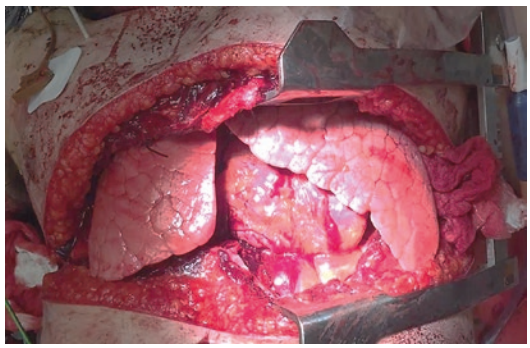

Fig. 20.2 Left antero-lateral thoracotomy with pericardial exposure using Finochietto retractor. (Courtesy of Richard Mullins, MD)

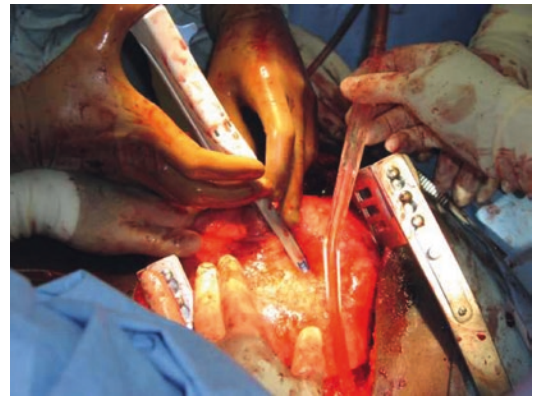

Fig. 20.3 Left antero-lateral thoracotomy with lung exposure and stapling with the GIA linear stapler to control hemorrhage. (Courtesy of Gregory J. Jurkovich, MD)

Complications

There are many technical complications that can occur during the performance of a resuscitative thoracotomy. This is a highly complicated and technical procedure that should not be undertaken unless there is the expertise to complete the resuscitation and operative repairs. The most common complications are listed below:

- *Injury to phrenic nerve:* When you initially "tent" the pericardium, cut it longitudinally to avoid injury to the phrenic nerves which runs lateral to the walls of the pericardial sac.
- *Aortic cross-clamp failure:* This clamp is difficult to place and even more difficult to maintain in position. Additionally, the clamp and exposure of the aorta can injure the aorta and cause exsanguinating hemorrhage, or injure the esophagus. To help identify the esophagus, an oral or naso-gastric tube should be placed. Only the two mentioned vascular clamps should be used on the aorta.
- *Rib fractures:* These occur if the rib spreader is opened too rapidly.
- *Lung injury:* Aggressive entry into the chest can injure the underlying lung.
- *Cardiac injury:* Great care must be taken, opening the pericardium; otherwise the

heart will be cut. If the patient has had a prior history of cardiac surgery, the pericardium will be stuck to the heart, and opening the pericardium in an emergency situation is futile.
- *Infection:* These are emergency procedures. Infection risks are higher. Great care should be taken to maintain sterile technique.

Keys to Success, Perils, Pitfalls

Below are listed several key tips for the experienced provider to successfully perform a resuscitative thoracotomy.

- *Experienced Provider and Hospital Resources:* The emergent thoracotomy is indicated in a small patient population and therefore not routinely performed, meaning provider experience with this procedure may be minimal. Hence, experience with elective thoracotomy and thoracic surgery is generally considered essential to obtain hospital credentials to perform an EDT. Additionally, many hospitals may not have access to trauma or cardiothoracic surgeons if ROSC is established; therefore, EDT should never be performed unless the hospital has the resources to provide full and comprehensive care following the procedure. EDT patients are never transferred to another hospital from the emergency department. The risk of death during transport is too high. Considering your resources is key to determining the appropriate place and time for this procedure.
- *Failure to Have a Plan.* A resuscitative thoracotomy has distinct indications because there are only a few injuries that can be addressed by opening the chest. Having a plan based on the mechanism of injury is key to efficiency. Key activities: Stop major intra-thoracic hemorrhage from the lung or great vessels; diagnose and treat tamponade; cross-clamp the aorta if bleeding below the diaphragm is suspected; assure adequate lung ventilation is occurring; perform internal cardiac massage while massive transfusion occurs.
- *Failure to Treat Tamponade*: Avoid this by opening the pericardium as described above and fully exposing the heart. This is particularly essential in penetrating wounds to the vicinity of the heart and mediastinal traversing wounds.
- *Failure to Secure the Aortic Cross-Clamp*: This clamp is difficult to apply and secure. Rechecking its position and confirming its location is essential.
- *Failure to Stop Pulmonary Hemorrhage:* A pulmonary hilar twist can rapidly achieve hilar vascular control and prevent systemic air emboli in a devastating lung injury. For significant lung injuries, begin by dividing the inferior pulmonary ligament followed by the "hilar twist," a rotation of the entire lung 180 degrees.
- *Iatrogenic Damage to the Heart and Lungs*: Damage to the heart and lungs can occur during the initial opening into the chest and opening the pericardium. Prior thoracotomy or cardiac surgery makes this highly likely.
- *Intercostal and Internal Mammary Arterial Bleeding:* The internal mammary arteries are transected if the incision crosses the sternum. The intercostal arteries can be injured during chest opening or from rib fractures. These vessels may not bleed until return of circulation and measurable blood pressure occurs, causing delayed and massive hemorrhage.
- *Cardiac Perforation*: Perform internal cardiac compressions with the flat surface of two hands. Never with the thumb or finger.

CPT Coding

- CPT 32110: Thoracotomy, with control of traumatic hemorrhage and/or repair of lung tear
- CPT 32160: Thoracotomy, with cardiac massage
- CPT 32100: Thoracotomy, with exploration

Summary

The emergency department thoracotomy (EDT), or resuscitative thoracotomy, is performed in patient's in extremis as a last resort and is often only salvageable for evacuation of cardiac tamponade, direct intrathoracic exsanguination, facilitation of open cardiac massage, and cross-clamping of descending aorta to increase perfusion to the brain and heart [3].The EDT remains the most polarizing and controversial procedure that providers perform given its risk of exposure to hospital personnel, limited benefit in certain patient populations, and need for ready access to experienced specialized surgeons. The role of the advanced practice provider is readily expanding, and this chapter provides a guide for the APP to assist in informed decision-making for appropriate patient populations, assist at the bedside during the procedure, and have a working knowledge of common complications seen in this potentially life-saving procedure.

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21 Extracorporeal Membrane Oxygenation and Extracorporeal Life Support

William F. Holecek III

Introduction

The era of open-heart surgery began in the 1950s with the development of the cardiopulmonary bypass (CPB) machine [1]. Extracorporeal membrane oxygenation (ECMO) is a simplified, portable adaptation of this technology. By simplifying the technology, ECMO provides cardiac and/or pulmonary support beyond the operating room for extended periods of time. ECMO continues to redefine the way we think about life support. This chapter will focus on the use of ECMO as a rescue therapy in the adult population.

Indication

There are several different variations of ECMO. Each mode of ECMO has its own specific indications. The following will highlight two main types of ECMO, venous-venous (VV) ECMO and venous-arterial (VA) ECMO.

VV ECMO

VV ECMO is the mode of choice for patients with primary respiratory failure. This mode oxygenates the blood and removes carbon dioxide. The major difference between VV and VA is that during VV the blood does not bypass the heart. This means that patients being placed on VV must be hemodynamically stable. The most common condition for VV ECMO is patients with severe hypoxemia. Patients should be considered for ECMO when a PaO2 to FiO2 ratio reaches less than 150 on 90% FiO2. If the PaO2 to FiO2 ratio is less than 100 on 90% FiO2, then ECMO is indicated [2]. Other respiratory conditions that may warrant VV ECMO include:

- Severe air leak syndromes
- Intubated patients awaiting lung transplant
- Patients with sudden respiratory collapse secondary to a pulmonary embolism or airway obstruction

VA ECMO

VA ECMO is for patients with cardiogenic shock that have failed to respond to alternative therapies. Conventional therapy for cardiogenic shock includes adequate volume resuscitation, administration of vasopressors and inotropes, and mechanical support devices such as an intra-aortic

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balloon pump (IABP) or temporary left ventricular assist device (LVAD) [3]. Common conditions include:

- Myocardial infarctions
- Peripartum cardiomyopathies
- Decompensated chronic heart failure
- Cardiogenic shock status post open-heart surgery
- Patients receiving adequate cardiopulmonary resuscitation (CPR) without sustained return of spontaneous circulation (ROSC) with a reversible cause

There are also case reports supporting elective use of VV or VA ECMO as a support device during procedures where the heart or lungs could be temporarily compromised such as [4]:

- Extensive bronchoalveolar lavage
- Operations on the trachea
- Coronary artery occlusion procedures

The list of possible indications continues to grow rapidly as the technology improves, but the one constant that must be considered is reversibility of disease. The primary disease must be reversible for ECMO to be effective.

Contraindication

The major contraindication to the use of ECMO is irreversibility of the primary disease. As mentioned above this is a major caveat that cannot be taken lightly. It is of the utmost importance that patients and their family understand that ECMO is not a cure. The primary disease must be treatable in order to be able to successful wean off ECMO support. Conditions such as the following are absolute contraindications [4]:

- Terminal illness
- End-stage malignancy
- Unrecoverable heart failure without the ability to receive a ventricular assist device (VAD) or heart transplant
- End-stage organ dysfunction such emphysema or cirrhosis
- Prolonged CPR without adequate perfusion and brain death
- Severe aortic regurgitation/aortic dissection (VA ECMO)

Relative contraindications include:

- Advanced age
- Increased bleeding risk
- Recent or expanding central nervous system bleeding
- Inability to accept blood products
- Limited vascular access

Risk/Benefit

ECMO is far from a benign endeavor. ECMO should only be considered when the risk of mortality without treatment is greater than 50%. In most cases the benefit of ECMO will outweigh the risk if the patient's risk of mortality without treatment is above 80% [4].

Preparation

Before initiating ECMO it is important to understand the basic principles. ECMO starts by placing large bore intravascular catheters (cannulas) in a patient's central circulation. These cannulas siphon blood from the patient into a series of tubing (the circuit). Within the circuit there is a pump to circulate the blood and a membrane lung, which is often referred to as an oxygenator. The membrane lung oxygenates the blood and removes carbon dioxide. After passing through the oxygenator, the blood is then returned to the patient through a second cannula.

The placement of the cannulas determines what type of support the patient is receiving. Patients on VA ECMO will have one cannula in the venous system draining blood and the second cannula in the arterial system returning blood. This setup allows for full cardiac and pulmonary support. The blood literally bypasses the heart and lungs.

Patients receiving VV ECMO will have both cannulas in the venous system. The blood return-

ing to the right side of the heart will already be oxygenated and the CO2 removed. The blood will still circulate through the pulmonary vasculature but does not rely on the lungs to be functional.

After determining what type of support the patient needs, the next step is to create a cannulation strategy. There are several options for placement of venous and arterial cannulas.

Venous access sites include:

- Internal jugular veins
- Femoral veins
- Right atrium

Arterial access sites include:

- Femoral artery
- Axillary artery
- Ascending aorta
- Pulmonary artery (This setup is a right ventricular assist device (RVAD) and not a true VA ECMO)

Procedure

The cannulation can be performed percutaneously using Seldinger technique, surgically via cutdown and direct visualization, or surgically with central cannulation and an open chest.

Percutaneous Cannulation Procedure

- Step 1: Get your gear—initial setup and preparation (Fig. 21.1).
  - Quiet down the room.
  - Prep the patient with full barrier, sterile scrub, and drapes.
  - Heparinize the patient: 3000–5000 units (100 units/kg).
  - Fill a large, sterile bowl with NS and have a 60 ml bulb syringe ready for cannula irrigation and flushing.
  - Initial vascular access.

    Be efficient: While setting up the circuit and the team is gathering supplies, start by obtaining vascular access.

Fig. 21.1 Placement of ECMO at patient's bedside

    Initial access: Place a right femoral CVC, a left femoral a-line, and a right IJ CVC under ultrasound guidance. If you already have an a-line, you can suture a femoral arterial wire in place for future use.

    At this time, also determine any other lines that need placement and determine site of access (arterial, CVC, or PA catheter).

    Pitfall: Not placing these lines under ultrasound guidance, as we all know, in the critically ill or critically hypoxic patient, arterial blood can look the same color as venous blood. Don't count on appearance alone. Even using a pressure column can be misleading.

    Double check: Confirm wire placement in the lumen of the vessel.
  - Cannulation equipment

    Cannula

    Venous cannula: sizes range from 23 to 29 French steel wire-reinforced

    Arterial cannula: sizes range from 19 to 21 French steel wire-reinforced

    Different insertion lengths: range from 15 to 55 cm (depending on manufacturer) (Fig. 21.2)

    Lock introducer: The size of the venous cannula directly determines blood flow. The largest possible venous cannula should be used to maximize flow and easily achieve target output:
  - Some will choose cannula size on flow goals alone.

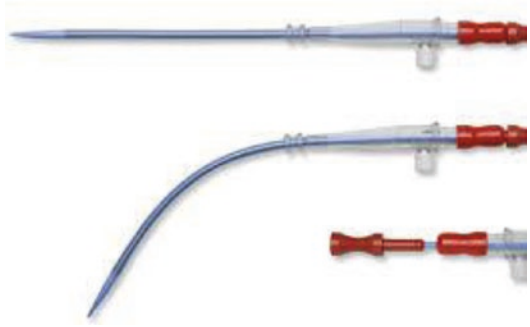

Fig. 21.2 Femoral arterial cannulas. Available in sizes 16 French to 24 French

  - Some data to suggest the use of ultrasound may be helpful to determine vessel lumen size and appropriate cannula size [5].
- Venous cannula length targets:
  - Femoral: Distal tip rests in the IVC, generally at the level of T10–T11. You do not want to advance the cannula past the hepatic vein, as this can cause an obstruction and hepatic congestion.
  - Internal jugular: Distal tip to rest in the SVC.
  - Try to measure the lengths with the cannula beforehand, so when advancing, you know when to stop!

    Note: For VV ECMO, circuit of a femoral drainage (deoxygenated blood) and internal jugular return cannula (oxygenated blood) is believed to provide less recirculation than the reverse (see Recirculation).

    Dilators: Series of 8, 12, 16, 20, and 24 French dilators
- Step 2: Dilate up the initial insertion sites.
  - Insert the 150-cm guide wire through the distal port of the femoral CVC.
  - Remove the CVC and hold pressure over the insertion site to prevent excessive bleeding.
  - Load the 8 French dilator onto the introducer wire and advance it just to the skin.
  - Prior to advancing the dilator, you will have to extend your initial incision.

    Extend the incision by about 1 cm just smaller than the size of your dilator.

    This will provide adequate hemostasis each time you dilate the soft tissue.
  - Introduce the dilator in a corkscrew-wise fashion, advancing the dilator at the level closest to the skin.
  - As you advance the dilator, periodically check to make sure your guide wire freely moves within the dilator itself. If you develop a kink or difficulty passing the dilator, you run the risk of lacerating the vessel.
  - Repeat this step for each dilator up until you reach the appropriate size for your chosen cannula (Fig. 21.3).
- Step 3: Inserting the ECMO cannula.
  - After your final dilation, load your introducer onto the 150-cm guide wire.
  - Advance the introducer through the soft tissue, far enough that you actually dilate the wall of the femoral vein.
  - Remove the introducer and hold a significant amount of pressure.
  - Load your venous cannula onto the introducer, then onto the 150-cm guide wire.
  - Finally, advance your cannula to the predetermined distance.
  - Remove the dilator and wire and double clamp the open end of the cannula.
  - Flush your cannula with a copious amount of sterile saline.
  - Pearl: There is a slight step-off between the cannula and the introducer due to the actual thickness of the wire-reinforced cannula itself. If your dilation is inadequate, this step-off can get hung up on the soft tissue while attempting to insert it into the vessel.
  - Pearl: You can use your ultrasound to visualize cannula placement in the IVC! Use it.
- Step 4: Connect to the cannula to the circuit (Fig. 21.4).
  - Check the circuit tubing: Remove all twists and coils. Make sure that there is plenty of length between the circuit and the cannula themselves.
  - Irrigate the ends of the tubes: As you attach the cannula to the circuit tubing, use the bulb syringe to irrigate the ends to prevent air from getting trapped in the tubing.
- Step 5: The same steps above for the return cannula.

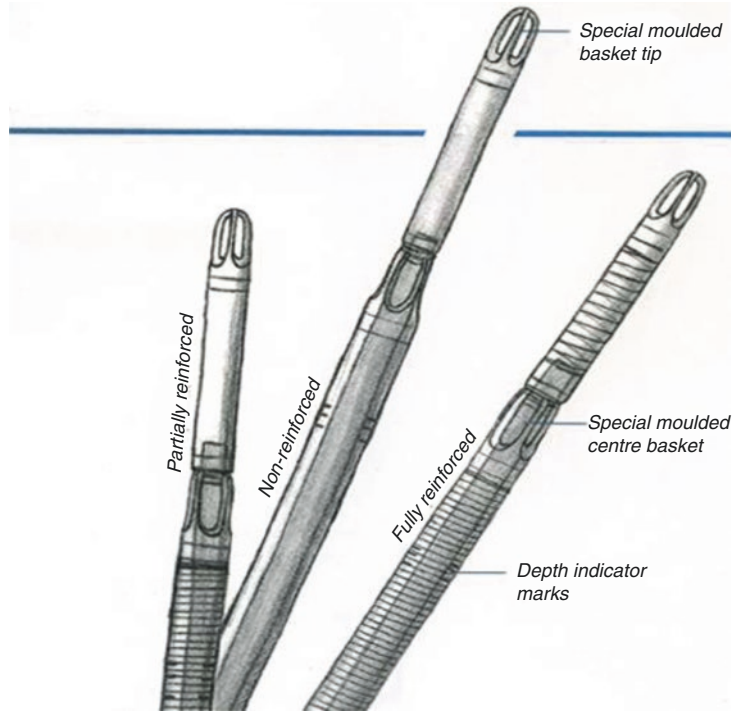

Fig. 21.3 Single stage venous cannulas. Available in multiple sizes from 22 French to 34 French

Fig. 21.4 ECMO circuit: Top left: membrane oxygenator, oxygenates blood and removes CO2 as blood passes through it. Bottom right: centrifugal pump, pumps blood through the circuit using a rotating impeller that spins creating negative pressure in the pump head

- Step 6: Turn on the circuit.
  - Goal flow for VV ECMO (in adults) about 50–60 cc/kg/min. You can start at around 2 l and titrate up, usually to a goal of 4–5 lpm.
  - Start the sweep at about 2 lpm (for CO2 clearance) and titrate.
- Step 7: Cleanup and confirmation.
  - Order a chest and abdominal XR to confirm cannula location (Fig. 21.5).
  - While you are waiting, you can also perform a bedside ultrasound to visualize the cannula tip in the IVC.
  - Make sure your cannulas are secure. Usually, place at least two stabilizing sutures (for IJs) and three to four for the femoral cannula with a 0 silk suture. Cover the sites with a sterile dressing [5].

Open Cannulation/Direct Visualization

If time allows, CT angiography of vessels should be reviewed prior to cannulation. For those patients that are noted to have severe peripheral

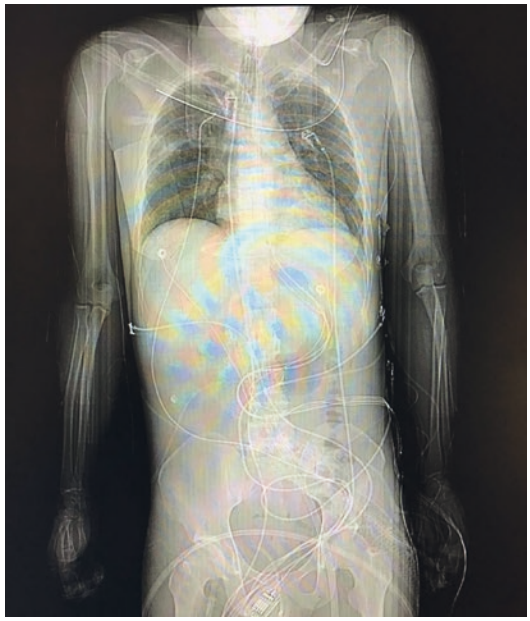

Fig. 21.5 CT scout film showing venous cannula in left femoral vein with distal tip terminating in the inferior vena cava near the right atrium and arterial cannula in the right femoral artery with distal tip terminating in the right iliac artery

artery disease or other contraindication for femoral cannulation, axillary cannulation using a side graft of Dacron sewn to the artery allows cannulation by "stovepipe" and reduces risk of limb ischemia. After removal of the cannula, a "diamond" patch of Dacron is used to repair the artery to reduce risk of future stenosis.

Open Chest Cannulation

For those patients who undergo open-heart surgery and are unable to be weaned off of the bypass circuit, there is indication for central cannulation. In this technique, the aortic and right atrial cannula is directly connected to the ECMO circuit in VA flow. The chest is then covered and the cannula are secured to the patient.

Weaning Off ECMO

The final step is weaning the patient off ECMO. For patients with isolated respiratory failure, indications that the patient may be ready for weaning from ECMO would be improvements in pulmonary compliance, arterial oxygen saturation using standard ventilation modalities, and improved radiographic appearance.

This is accomplished by slowly reducing gas exchange through the oxygenator in the circuit and then eventually stopping all gas exchange. Although ECMO circulation continues, no gasses are exchanged. If the patient tolerates this, they may be decannulated (Fig. 21.6).

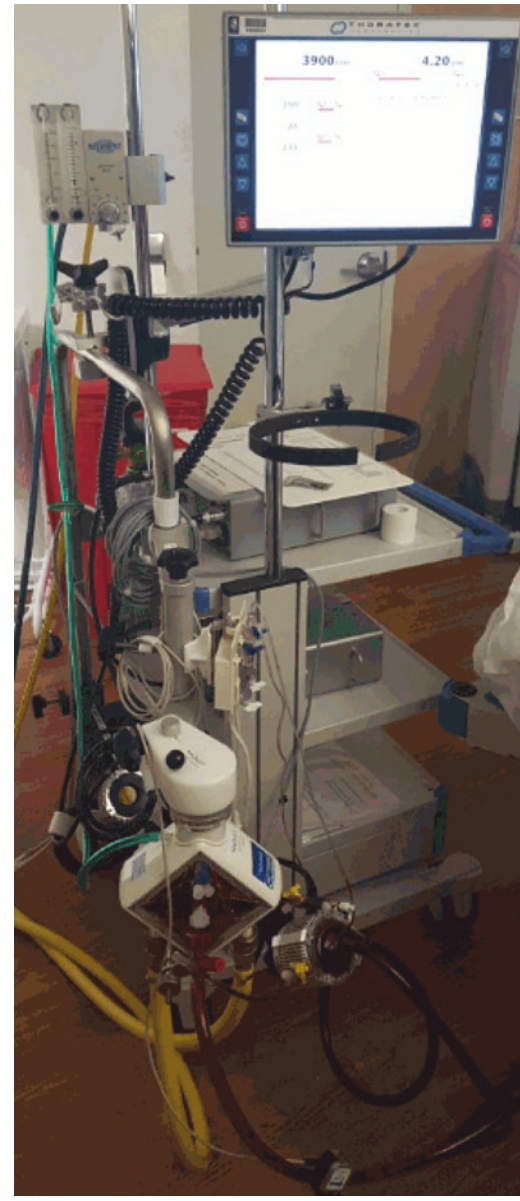

Fig. 21.6 ECMO at the bedside

Similarly, for patients on ECMO for cardiac failure, indications that the patient is ready to come off of ECMO would be enhanced aortic pulsatile wave form and improved left ventricular function. However, the technique for weaning is different than in VV ECMO. VA ECMO trials can be performed by temporary clamping of both the drainage and infusion lines while allowing the ECMO circuit to circulate through a bridge between the arterial and venous limbs. This bridge prevents thrombosis of stagnant blood within the ECMO circuit. Because of the increased risk of thrombus formation in the VA circuit, VA ECMO weaning trials are usually shorter than in VV ECMO and require constant heparinization of the circuit during weaning. If the patient continues to fail, they may be candidates for a ventricular assist device (VAD) [6].

Complications

ECMO is an extremely invasive procedure with multiple potentially catastrophic complications associated with its use. Patients should have failed traditional therapy before any consideration is made to be placed on ECMO.

Bleeding

The most common complication encounter is bleeding. In order to prevent the blood from clotting in the ECMO circuit, patients are given boluses of heparin during initiation and are typically kept anti-coagulated while on ECMO. The ECMO pump also has a tendency to cause platelet dysfunction. These factors can lead to significant increased risk of bleeding requiring frequent transfusions.

Neurologic Injury

According to the ELSO Registry, approximately 15% of patients who received VA-ECMO developed neurological complications. Among the 4522 adult patients supported with VA-ECMO from 1992 to 2013, 358 (7.9%) had brain death, 161 (3.6%) had a cerebral infarction, 83 (1.8%) developed seizures, and 80 (1.8%) were found to have cerebral hemorrhage [7].

Vascular Injury

Vascular injury can occur during the cannulation phase or at any point during the ECMO run. Injuries include limb ischemia, compartment syndrome requiring fasciotomies or potential amputation, vessel laceration or dissection, pseudo-aneurysm, and AV fistula formation.

Keys to Success, Perils, and Pitfalls

The most dreaded outcome for experienced ECMO clinicians is having a non-viable patient on ECMO with no exit strategy. To avoid this, it is helpful to have a checklist performed to thoroughly assess a patient prior to initiating ECMO. Institution should also have policies in place regarding necessary criteria for ECMO candidates.

Another catastrophic complication that can occur is anoxic brain injury. This can occur in patients receiving VA ECMO through a femoral-femoral cannulation due to a phenomenon known as the mixing cloud. In VA ECMO a portion of the blood will not be siphoned off and will go through the native cardiac and pulmonary circulation.

If the patient's cardiac function returns or improves prior to the lung function improving, then the blood being ejected from the left ventricle will be deoxygenated. If the pressure generated by the left ventricle exceeds the pressure generated by the ECMO flow, one of the first organs to receive the deoxygenated blood will be the brain. To ensure this does not happen, the pulse oximeter and arterial line must be placed on the patient's right upper extremity. The right upper extremity receives blood from the brachial cephalic trunk, which also feeds the right carotid artery, alerting you to any potential for anoxic injury early and allowing for intervention.

As we discussed above, VA ECMO does not completely bypass the native cardiac circulation. This can present a problem if a patient is asystolic. The blood returning to the left ventricular can become stagnant and cause a LV thrombosis. There are several potential ways to avoid this. One option is to add an additional drainage cannula directly into the left ventricle as a vent to remove any blood. Another practice is to use a temporary LVAD such as an Impella to pump blood out of the LV.

Patient on femoral-femoral VA ECMO is also at risk for limb ischemia. The femoral arterial cannula can potentially occlude flow from going to the distal portion of the lower extremity and lead to compartment syndrome. Patient should be monitored every hour with neuro-vascular checks. If the extremity appears to be at risk, then placement of an additional arterial cannula that sends blood distally can resolve the issue (distal perfusion cannula).

Recirculation

Recirculation is the inadvertent siphoning of oxygenated blood from the circuit that is pulled into the venous cannula. This is common during ECLS when using VV circulation only and can occur in both single and double cannula circuits. Due to mixing of the blood, circuit SVO2 is invalidated. Additionally, when recirculation occurs, the effectiveness of the VV circuit is reduced, as that portion of the blood never reaches the native circulation. To counteract this effect, higher flow rates are required; however, flows >400–500 ml/min will result in further recirculation and may actually reduce oxygenation. Clinically, recirculation is evidenced by falling arterial oxygen saturation (SPO2) and concurrent rise in circuit mixed venous oxygenation (SVO2). Troubleshooting may simply involve repositioning the patient's head when a double-lumen cannula is used. Recirculation in two-cannula systems is likely due to the cannula being in close proximity and may be solved by cannula repositioning. Another option would be to change the direction of flow with a decrease in the incidence of recirculation using drainage from a femoral vein and return to the IJ cannula [6].

CPT Coding

CMS CPT codes for ECMO

- 33947 ECMO/ECLS initiation veno-arterial
- 33946 ECMO/ECLS initiation veno-venous
- 33948 ECMO/ECLS daily mgmt-venous
- 33949 ECMO/ECLS daily mgmt-veno-arterial
- 33952 ECMO insertion peripheral cannula (6 years and older)
- 33966 ECMO removal peripheral cannula (6 years and older)
- 33956 ECMO insertion of central cannula by sternotomy (6 years and older)
- 33986 ECMO removal of central cannula by sternotomy (6 years and older)

CMS.gov. 7/5/2019

Summary

ECMO remains an option for those patients who fail conventional ventilation modalities and those in cardiogenic shock. The number of patients being placed on ECMO and number of centers offering ECMO continue to grow annually proving its utility. However, we should remain cautiously optimistic regarding the future of ECMO. The most important lesson to take away is to understand the limitations of ECMO. While it has the potential to saves the lives of many critically ill patients, it also has the ability to severely strain healthcare resources.

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Thoracentesis

22

Kathleen Hanlon and Daniel P. Mulcrone

Introduction

Pleural effusions are diagnosed in more than one million patients annually in the United States, with varying etiologies [1]. Almost 200,000 thoracenteses are performed, either for diagnostic or therapeutic purposes. Cytology of pleural fluid can provide information as to whether the effusion is transudative or exudative and, when a therapeutic thoracentesis is performed, can palliate the cardiopulmonary sequelae of an effusion. The purpose of this chapter is to provide a detailed account regarding the risks and benefits of a thoracentesis, as well as a step-wise approach to performing the procedure.

Indications

The primary goal of a thoracentesis is the removal of pleural fluid. The procedure can be done to obtain samples for cytology and culture to further characterize the underlying etiology of the effusion, which will then be categorized as being either transudative or exudative. Causes commonly encountered in the critical care setting are listed in Table 22.1. Very large pleural effusions can result in pulmonary and, eventually, cardiac compromise. Thoracentesis with evacuation of a large volume of pleural fluid can provide therapeutic relief for the patient.

Table 22.1 Common etiologies of transudative and exudative pleural effusions encountered in the critical care setting

Causes of pleural effusions	
Transudative	Exudative
Heart failure	Infectious
Nephrotic syndrome	Pancreatitis
Hypoalbuminemia	Hemothorax
Atelectasis	Iatrogenic
Iatrogenic	Acute respiratory distress syndrome
Malignancy	Malignancy

Contraindications

With the exception of patient refusal, there are no absolute contraindications to thoracentesis, especially when proper technique is followed meticulously. However, one must exercise clinical judgment in critically ill patients when evaluating the need and risks for the procedure, including

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the level of expertise of the clinician. Relative contraindications include coagulopathy or bleeding diathesis, as well as cardiac instability not caused by the effusion. While mechanical ventilation is not a contraindication, a thorough understanding of the mechanics of positive pressure ventilation is crucial to minimize complications. Finally, thoracentesis should not be attempted at a site of active cutaneous infection, such as cellulitis or herpes zoster.

Risks/Benefits

The most common risk associated with thoracentesis is pneumothorax, with an incidence of 6% [2]. Other complications include bleeding, infection, solid organ injury, re-expansion pulmonary edema, and death. Additionally, allergic reaction to lidocaine or skin prep solutions should be considered.

As previously discussed, performing a thoracentesis can aid in determining the underlying etiology and subsequent therapy of a pleural effusion. Clinical benefits include improvement in pulmonary status and resolution of dyspnea in patients with large effusions.

As with any procedure, the risks and benefits must be weighed, as must operator skill and clinical stability of the patient.

Preparation

Prior to initiation of the procedure, a thorough physical examination should be performed. The location of the effusion can be determined based on dullness to percussion, diminished or absent breath sounds, and diminished or absent tactile fremitus. Imaging of the patient should also be reviewed, whether it be plain film chest X-ray (Fig. 22.1), computed tomography, or ultrasound. Lateral decubitus chest X-ray will usually allow for visualization of layer, and chest CT will demonstrate loculations. The combination of physical exam findings and imaging will aid in determining the optimal site of insertion of the thoracentesis needle.

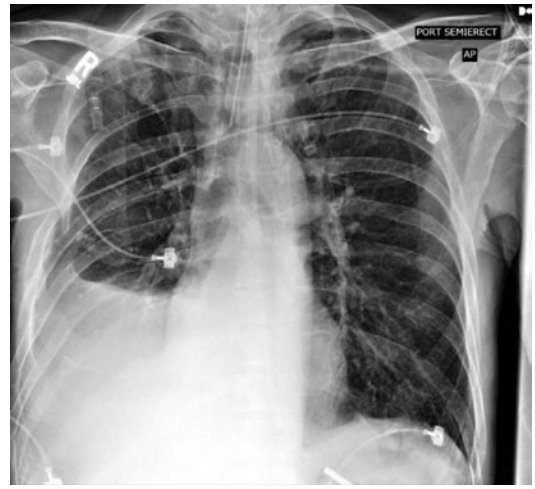

Fig. 22.1 Portable, semi-upright chest X-ray with right-sided pleural effusion

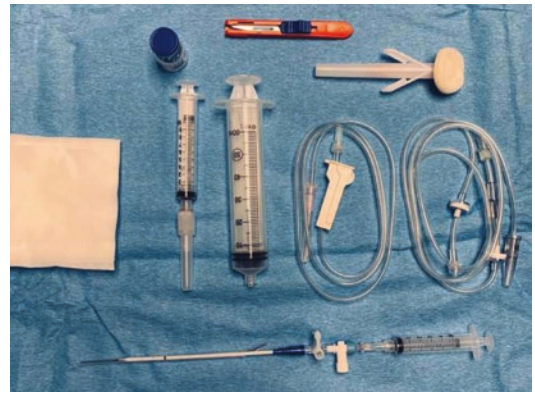

Fig. 22.2 Thoracentesis equipment including cleansing solution, lidocaine, syringe with needle for injection, an over-the-catheter syringe with stop-cock and one-way check valve, 60 ml syringe, scalpel, tubing, and gauze. Pre-packaged, commercially available thoracentesis kits are available

Thoracentesis equipment required regardless of the reason for the procedure are illustrated in Fig. 22.2. When performing the procedure for diagnostic purposes only, a large 35–60 ml syringe will be needed for aspiration, as well as specimen tubes. If the procedure includes a therapeutic component, a three-way stop-cock, high-pressure drainage tubing, sterile occlusive dressing, and large evacuated containers will also be needed. If utilizing ultrasound, ensure appropriate probes are available – either linear or

phased array low-frequency transducer, as well as ultrasound gel.

Depending on the level of operator experience, a more experienced provider should be present for assistance, if needed. Nursing staff should also be available to assist with positioning awake and mobile patients on the edge of the bed, with arms resting on a bedside table in front of them. Alternatively, if the patient is unable to sit upright, he or she should be positioned supine with the ipsilateral arm extended above the head to expose the midaxillary line. Additionally, minimal sedation with an anxiolytic may be required, such as a benzodiazepine. Nursing staff should remain in the room for the entire procedure to assist with monitoring of the patient.

Procedure

As with any procedure, thoughtful and deliberate preparation is key to minimization of both complications and patient discomfort. An informed consent detailing the risks, potential complications, and benefits of the procedure should be obtained whenever possible. A time-out should be performed prior to the start of the procedure, in compliance with Joint Commission's Universal Protocol, to verify the correct patient, procedure, and site.

Equipment should be assembled prior to initiation of the procedure. Commercially available thoracentesis kits (such as from Arrow-Clarke) will provide the operator with the necessary equipment for a diagnostic thoracentesis, save for a large (35–60 ml) syringe. The patient should be positioned at this time as well. If the patient is able to sit on the edge of the bed and a posterior approach will be attempted, care must be taken to avoid the posterior intercostal arteries (ICAs) (Fig. 22.3). The ICA courses below the inferior border of the rib in the subcostal groove. It has been noted that the ICAs are more exposed more medial to the spine and in more caudal intercostal spaces. However, 97% of ICAs were found to be completely shielded at 6 cm lateral to the spine [3]. Ultrasound can be utilized with Doppler imaging to assess the location and tortuosity of the ICA and prevent hematologic complications associated with arterial laceration. If the patient is supine, the "triangle of safety" (Figs. 22.4 and 22.5) should be utilized for the needle insertion

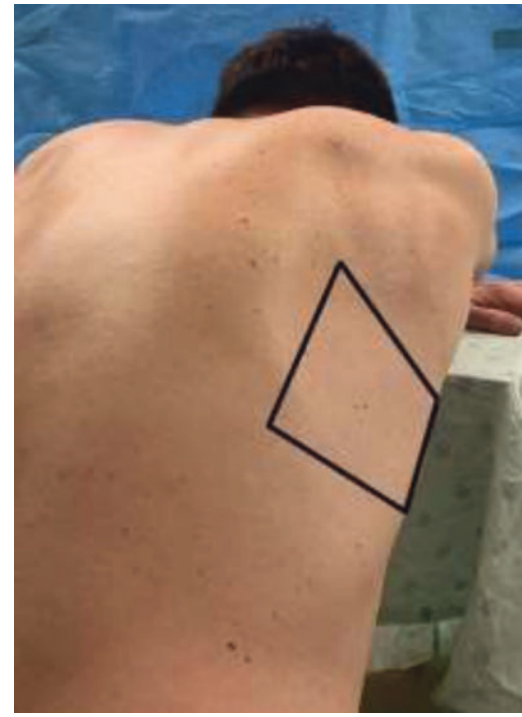

Fig. 22.3 Posterior upright approach with subscapular insertion area demarcated

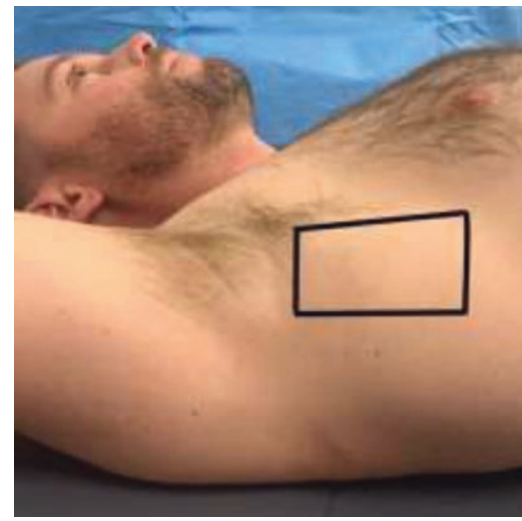

Fig. 22.4 Supine approach with triangle of safety demarcated

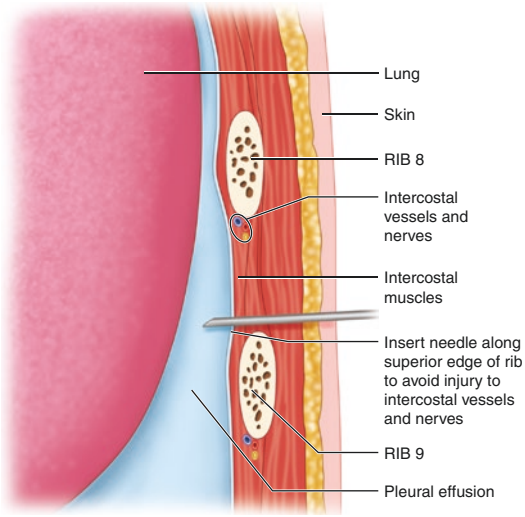

Fig. 22.5 Needle insertion in supine patient

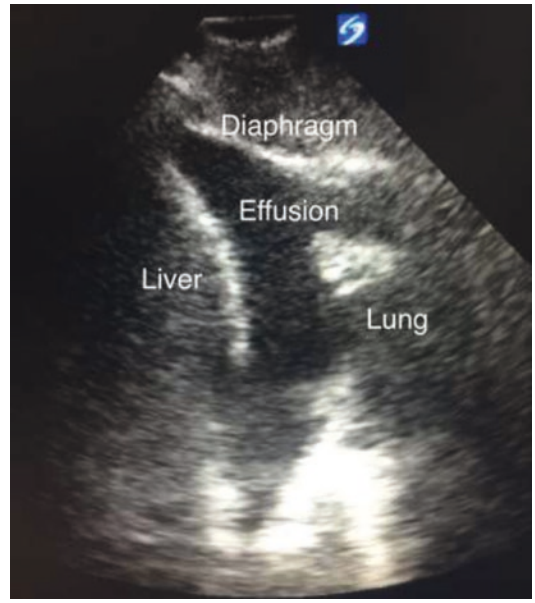

Fig. 22.6 Ultrasound image of a right-sided pleural effusion demonstrating the anatomical boundaries of the liver, diaphragm, and lung

point. It is bordered by the lateral edge of the pectoralis major, the lateral edge of the latissimus dorsi, the fifth intercostal space, and the base of the axilla. To minimize risk of complications, such as solid organ injury, it is imperative to remain above the nipple or above the sixth intercostal space.

Regardless of the approach, ultrasound imaging performed prior to the procedure should be done with the probe marker cephalad. An image of a pleural effusion will demonstrate an anechoic space within the anatomical boundaries of the chest wall, lung, and diaphragm, as well as subdiaphragmatic organs, such as the liver or spleen (Fig. 22.6). Dynamic changes can be observed, such as lung movement and mobile echodensities, within the fluid of the effusion [4, 5]. The insertion site should be marked one to two intercostal spaces below the level of effusion while being mindful of the anatomic landmarks previously outlined.

The skin is prepped with the sterile cleansing solution and a sterile drape is placed. The epidermis is anesthetized with 1% lidocaine with a 25-gauge needle. The needle is then exchanged for a 22-gauge needled and marched along the superior surface of the rib, so as to avoid the neurovascular bundle which courses along the inferior border (Fig. 22.7). Lidocaine is injected in the periosteal space and the needle is advanced.

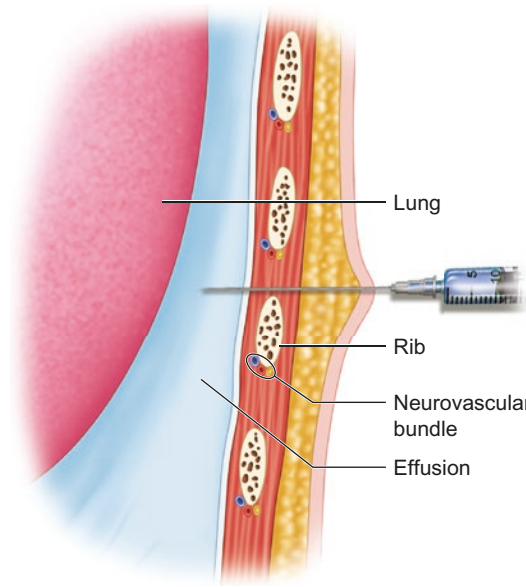

Fig. 22.7 Needle insertion above the rib

The plunger is withdrawn every 2–3 cm to ensure the needle is not intravascular. Once the needle enters the pleural space and pleural fluid is aspirated, lidocaine is injected to ensure the parietal pleura is adequately anesthetized. The depth of

the needle needed to enter the pleural space is noted and the needle is then removed [6].

When utilizing a pre-packaged thoracentesis kit, an 18-gauge over-the-catheter needle with a built-in check valve is available. A 35–60 ml syringe is attached to the hub of the needle, and a small incision is made with an 11-blade scalpel at the insertion site. The needle is held perpendicular to the patient and advanced along the anesthetized path with the operator withdrawing on the plunger continuously. Once pleural fluid is aspirated, the needle may be advanced up to 1 cm further to ensure its maximum diameter is within the pleural space. The catheter is then advanced over the needle and the needle, with the syringe attached, is removed. The built-in check valve ensures that no air is entrained into the patient.

If a pre-packaged thoracentesis kit is not available, an 18-gauge over-the-catheter needle with a syringe attached is utilized in the same fashion. Prior to removal of the needle, the patient should be instructed, if possible, to exhale completely and hold their breath. Once the needle has been removed and the catheter is in the pleural space, the open hub of the catheter should be covered with a gloved hand to prevent entrainment of air into the pleural space [4, 6].

A 60 ml syringe connected to a three-way stop-cock with the "off" position toward the patient is attached to the catheter hub. The stop-cock is opened to the patient, and the syringe with the appropriate volume of pleural fluid is aspirated for analysis.

Additional fluid may be drained, if necessary, for therapeutic purposes. Sterile drainage tubing is attached to the third portion of the stop-cock with its distal end connected to a large evacuated container. The stop-cock is then opened to the patient and the container to allow the drainage of pleural fluid. Alternatively, if an evacuated container is not available, a syringe pump method may be utilized. This consists of the operator aspirating pleural fluid into a large 60 mL syringe. Fluid should be drained until the patient's cardiopulmonary status improves.

When the procedure has been completed, the patient should, if possible, again be instructed to exhale and hold their breath while the catheter is removed. The site is then covered with an occlusive dressing. The patient should be monitored closely in the hours following for signs and symptoms of developing complications, such as dizziness, shortness of breath, hypotension, hypoxemia, or tachycardia. Development of cough is not uncommon as the lung re-expands. Following the procedure, a plain film chest X-ray should be obtained to evaluate the efficacy of the thoracentesis and for any immediate complications, such as an iatrogenic pneumothorax.

Complications

Complications associated with both therapeutic and diagnostic thoracentesis include pneumothorax, bleeding, solid organ injury, and infection. Bleeding, such as chest wall hematoma, insertion site bleeding, and hemothorax, has been documented. The incidence of clinically significant bleeding in a recent review was noted to be 1% [7]. A rare but potentially serious complication that has been associated with large-volume pleural fluid drainage is re-expansion pulmonary edema (REPE), for which there is a reported incidence of <1% [7]. While the underlying physiology of REPE is not well understood, expert consensus has historically recommended limiting drainage volume to no more than 1.5 L [8]. Large studies evaluating risk of REPE associated with volume of fluid removal are needed, but smaller studies suggest that the practice of limiting volume removal to 1–1.5 L should be revisited [9]. However, the operator should be mindful of the patient developing shortness of breath or chest discomfort when performing a large-volume pleural drainage and proceed with caution. Solid organ injury to the liver, diaphragm, spleen, and left ventricle has been noted as well [10].

Keys to Success, Perils, and Pitfalls

Keys to success include comfort and experience level of the provider, as well as attention to detail and proper technique. Inexperienced operators should be supervised until deemed proficient.

Patient positioning is crucial in minimizing risk and ensuring positive outcome of the procedure.

Both static ultrasound imaging for pre-procedural site determination and dynamic for procedural guidance are commonly utilized. A number of studies have demonstrated a decrease in complications associated with thoracentesis with ultrasound usage. The American Thoracic Society, Society of Thoracic Surgeons, and Society of Thoracic Radiology recommend utilization of ultrasound guidance to reduce the risk of pneumothorax in patients with malignant effusions undergoing thoracentesis [11]. Additionally, the Society of Hospital Medicine and the British Thoracic Society also recommend ultrasound for all thoracenteses performed to minimize risk of pneumothorax [12, 13]. A study investigating the accuracy of pleural puncture sites as determined by physical examination with follow-up ultrasound imaging revealed that 15% of clinically determined puncture sites would have resulted in a solid organ injury (liver, spleen, or lung) [10]. Furthermore, a recent retrospective chart review evaluated the risk of complications in patients undergoing thoracentesis with either ultrasound guidance of the procedure or ultrasound-guided site marking. They noted a significant decrease in rate of all complications associated with real-time ultrasound-guided thoracentesis (0.63% vs 6.89%) [14].

A complete, step-wise guide to ultrasonographic guidance of thoracentesis is beyond the scope of this chapter and requires proficiency in not only thoracentesis but ultrasound technique as well. The authors of this chapter recommend, at minimum, static ultrasound imaging to assess the location of the effusion and adjacent solid organ structures, such as the liver, spleen, diaphragm, and heart, prior to initiation of the procedure.

While there has historically been concern regarding risk of bleeding in patients with pre-procedural coagulopathy or thrombocytopenia, several studies have demonstrated that, with a skilled operator and ultrasound guidance, thoracentesis can be safely performed on patients with INR >1.5 and platelets $<50 \times 10^9$/L without reversal or product administration [15, 16]. Furthermore, antiplatelet agents such as clopidogrel have been noted to have a small risk of hemorrhage, with an incidence of bleeding of 0.04, following an ultrasound-guided thoracentesis [17]. There currently is minimal data regarding the safety of thoracentesis performed on patients taking NOACs. As such, every effort must be taken to ensure minimal chance of bleeding in this patient population.

Finally, while a post-procedure chest X-ray is not routinely performed in patients who are asymptomatic, the authors recommend imaging following completion of thoracentesis. This can be done with an ultrasound to assess for lung sliding and pneumothorax or a plain film chest X-ray. Patients who are symptomatic with shortness of breath, chest pain, dizziness, or hypotension should have chest X-ray done to evaluate for pulmonary edema, pneumothorax, or hemothorax.

CPT Coding

- 32554 – Thoracentesis, needle or catheter, aspiration of the pleural space; without imaging guidance
- 32555 – Thoracentesis, needle or catheter, aspiration of the pleural space; with imaging guidance
- 32556 – Pleural drainage, percutaneous, with insertion of indwelling catheter; without imaging guidance
- 32557 – Pleural drainage; percutaneous, with insertion of indwelling catheter; with imaging guidance

Summary

Thoracentesis is a commonly utilized procedure which aids in the evaluation and diagnosis of the underlying etiology of pleural effusions, as well as in alleviating the cardiopulmonary compromise seen with large effusions. While it is a relatively safe procedure, operator experience and adherence to meticulous technique are critical for success and limiting morbidity associated with the procedure.

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Tube Thoracostomy

23

Brian K. Jefferson

Introduction

In the chest cavity, the space between the parietal and visceral pleura is often referred to as a potential space, only allowing for a small amount of fluid to facilitate frictionless movement of the pleura during respiration [1]. That said, the accumulation of air (pneumothorax) and/or fluid (hydrothorax) can occur for multiple traumatic or nontraumatic reasons (Box 23.1). Regardless of the etiology, the presence of a pneumothorax or hydrothorax can become problematic in that less space is provided for full lung expansion, which can lead to hypoxia, ineffective gas exchange, and ultimately respiratory failure. In its most severe form, a massive hydrothorax or tension pneumothorax can lead to tension physiology whereby the vena cava is compressed, which leads to shock and, if not reversed, death. Thus, the mainstay of treatment for pneumothorax or hydrothorax is tube thoracostomy, or chest tube placement.

Box 23.1 Etiologies for Pneumothorax and Hydrothorax

Pneumothorax	Penetrating chest injuries
Hemothorax	Recurrent symptomatic pleural effusions
Empyema/ parapneumonic pleural effusions	Chylothorax
Bronchopleural fistula	Cardiothoracic surgery

Based on data from Ref. [6]

Historically, tube thoracostomy was achieved via surgical technique, whereby blunt dissection is carried out from the subcutaneous tissue to the pleura, followed by a controlled puncture into pleura to facilitate tube placement [2]. However, evolving literature has demonstrated that the modified Seldinger technique, a less invasive technique that involves a smaller incision and less tissue trauma, is associated with less pain, fewer post-procedure complications, and quicker recovery [1, 2].

In addition to technique, the tube size often varies, with larger tube sizes used for fluid removal, particularly in cases of trauma, as traditional thinking is that larger tubes are necessary to facilitate drainage of blood to prevent a retained hemothorax. However, several studies suggest that the use of smaller-sized tubes or even pig-tail catheters yields similar outcomes in

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terms of evacuation of blood with no increase in complications [3, 4].

This chapter will discuss the indications, complications, pertinent anatomy, procedure description (modified Seldinger and surgical techniques), and post-procedure management.

Indications

The primary indication to perform tube thoracostomy is the presence of a pneumothorax and/or hydrothorax. The presence of a pneumothorax requires further assessment. Typically, a pneumothorax that is less than 2 cm from the chest wall does not require chest tube placement and may be conservatively managed. However, a larger pneumothorax does require the insertion of a chest tube. And the presence of a tension pneumothorax, a pneumothorax with concomitant shock, may require initial chest decompression, particularly if there is a delay in chest tube placement [5].

Other indications for tube thoracostomy include penetrating chest injuries, hemothorax, recurrent symptomatic benign or malignant pleural effusions, pleurodesis, empyema, parapneumonic pleural effusions, chylothorax, bronchopleural fistula, and post-cardiac/thoracic surgery. Furthermore, chest tubes may be placed to facilitate intrathoracic therapy such as intrapleural fibrinolysis [6, 7].

Contraindications

No absolute contraindications exist for performing a tube thoracostomy, particularly in emergent situations [6]. However, certain relative contraindications, or considerations, do exist, including an uncorrected coagulopathy with an INR > 1.5 and a platelet count less than 50,000, that can predispose the patient to uncontrolled bleeding if a vascular injury occurs during this procedure [7]. Bleeding complications are rare, particularly with astute attention to anatomy and insertion technique. One must, however, pay particular attention to insertion technique when performing Seldinger technique in that inadvertent vascular or cardiac injury can occur [8]. In addition to bleeding, the presence of adhesions or pleural loculations typically necessitate the use of ultrasound for safe insertion. Placement without the use of ultrasound could place the patient at risk for injury [7].

Preparation

Procedural Equipment

As with all procedures, equipment preparation is the key to procedural success. Most healthcare institutions have sterile chest tube trays prepared (Fig. 23.1a, b and Box 23.2). Alternatively, commercial kits are available (Fig. 23.2). Because

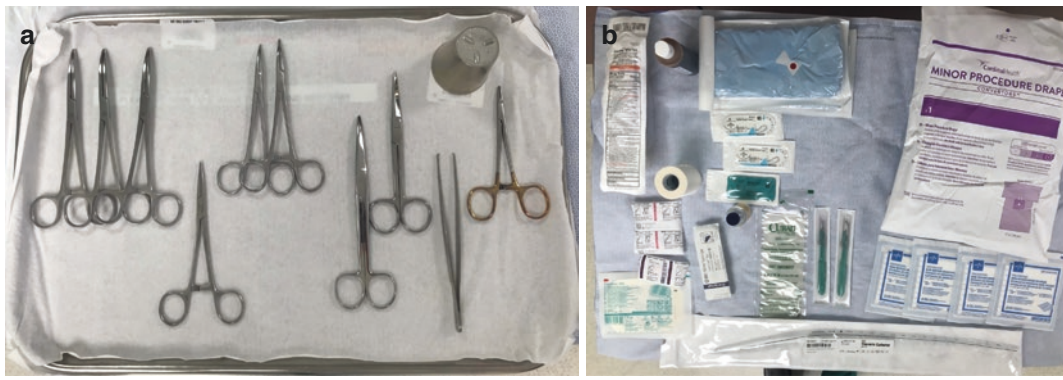

Fig. 23.1 (**a**, **b**) Sterile tube thoracostomy tray

Box 23.2 List of Supplies for Tube Thoracostomy Tray

Tissue forceps	Hemostat clamps, straight and curved
Dissecting scissors	Pean artery clamp
Heavy scissors	Stainless steel medicine cup
2-0 nylon suture	#0 silk suture
#10 and #15 scalpel	10 ml Luer-Lock syringe without needle
18ga needle	25ga 1 ¼" hypodermic needle
1% lidocaine without epinephrine	4 × 5 Tegaderm
4 × 4 drain sponges	ChloraPrep skin prep
Betadine solution	Large sterile drape
or sterile towels	Petroleum gauze
3 inch silk tape	

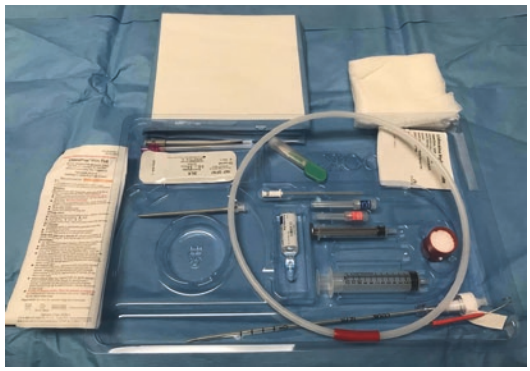

Fig. 23.2 Commercial tube thoracostomy tray

chest tube insertion is a sterile procedure, full protective sterile equipment, such as gowns, gloves, mask, and eye protection, are required.

The size and type of tube for insertion is dependent on the etiology for tube insertion. Tube sizes can range from 10 to 40 French. While, historically, larger-sized tubes (32–40 Fr) have been utilized for the evacuation of blood and/or air in trauma patients, consideration should be made for the use of smaller bore tubes such as 20–22 French [4, 9]. Similar consideration should be made for a parapneumonic effusion or empyema. Typically, pleural effusions and simple pneumothoraces only require a smaller bore catheter or pigtail insertion [6].

Thoracic Ultrasound

The chapter on EFAST provides a detailed review of the physiology and tenets of thoracic ultrasound which should be reviewed in the context of placing a chest tube for pneumothorax and/or hydrothorax. In the hands of a skilled operator, point-of-care ultrasound to detect a pneumothorax or hydrothorax can be quite effective and may obviate the need for additional radiographic exposure via chest radiograph [10]. In fact, point-of-care ultrasound can lead to initial diagnosis in up to 25 percent of cases [11]. Both the American College of Chest Physicians and the Society of Critical Care Medicine have endorsed the utilization of ultrasound in the ICU and put forth guidelines on usage and competency standards [12, 13].

Pertinent Anatomy

The pleura is composed of two membranes with a small amount of serous fluid between them to allow for frictionless movement with respect to the thoracic cage. The parietal pleura lines the inner wall of the thorax, while the inner, visceral pleura covers the lung surface [14]. From its most superior edge, the pleura lies approximately 2.5 centimeters above the medial third of the clavicle and inferior to the sternocleidomastoid muscle. Inferiorly, the pleura cross the eighth rib at the midclavicular line, the tenth rib at the midaxillary line, and the twelfth rib at the lateral border of the erector spinae [15].

Between each rib is the intercostal space (ICS), which is primarily composed of muscle and the neurovascular bundle. The intercostal muscles are divided into three layers. The two outer layers include the external and internal intercostalis. The innermost layer of muscles are made up of the sternocostalis, intracostal, and subcostal muscle layers. These muscles play a key role in respiration [16]. The neurovascular bundle is located within the subcostal groove of the superior rib. At the level of the first and second intercostal space, the intercostal artery (ICA) branches off from the superior

intercostal artery. For the third through eleventh ICS, the artery directly branches from the aorta. The posterior ICA courses with the intercostal space at the inferior rib margin where it is less protected by the subcostal groove more medially. As the ICA courses laterally, it assumes anatomic position within subcostal groove of the superior rib, at approximately 7 centimeters from the midline [17].

Procedure

Prior to the procedure, prophylactic antibiotic administration with Ancef or similar drug with Gram-positive coverage should be considered primarily for those patients who experienced penetrating thoracic traumatic injury [7]. Following informed consent and patient and site confirmation, the patient and equipment are prepared. Ideally, the patient will be in a supine position, in semi-Fowler's position with torso raised to approximately 45 degrees and the ipsilateral arm raised above the head [7, 18]. Once the patient is properly positioned, the site should be marked for needle entry with a marking pen. The area of safety for insertion of chest tubes, known as the "quadrangle of safety," includes the midaxillary line, pectoral groove, and space between the third and fifth intercostal space (Fig. 23.3)

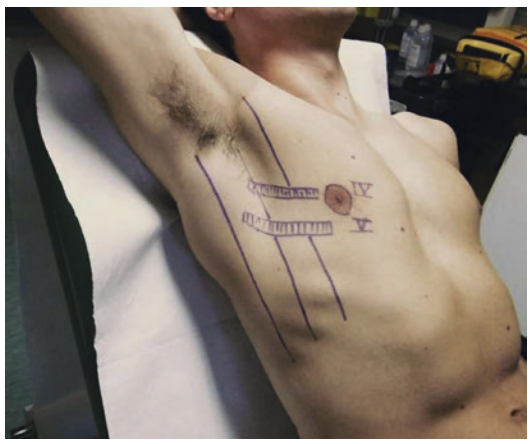

Fig. 23.3 Quadrangle of safety to determine safe area for tube thoracostomy. (Reprinted from Filosso et al. [8]. With permission from Elsevier.)

[8]. In the case of hydrothorax, pleural ultrasound can be used to identify the optimal position for needle entry [18]. Once the location is identified, the patient's skin should be properly prepped with 2 percent chlorhexidine or 10 percent iodine solution and then draped for a full sterile procedure [7]. Once this is accomplished, liberal use of local anesthetic, within acceptable dosing parameters, should be employed to anesthetize the skin, subcutaneous tissues, the inferior rib, and the parietal pleura.

Surgical (Blunt Dissection) Procedure

Prior to incision, the operator should palpate the area of the skin mark, to identify the superior and inferior ribs, and the corresponding ICS. Next an incision is made with a #10 blade scalpel. The incision should be large enough to insert one's finger through the skin and into the thoracic cavity [18]. Using the large Kelly clamps provided in the thoracostomy tray, the subcutaneous tissues should be spread down to the rib. This is best accomplished by inserting the closed clamps into the subcutaneous tissue, through the incision, and opening the clamps to spread the tissue. Then the clamps are closed again, carefully advancing the clamps and opening the clamps again. The repetitive process occurs until the rib is reached. Once the rib is palpable, the operator should place his/her index finger on the end of the closed clamp and insert through the incision and subcutaneous tract and over the inferior rib, pushing forward for a controlled entry into the pleural space. Upon entry, the operator should use the end of the clamps to spread open the pleura, to allow for passage of the chest tube into the thoracic cavity. Upon entry into the pleural space, the operator should notice a sudden release of air and/or fluid. Once this occurs, the forceps should be removed, and the operator should place his/her finger into the wound and into the pleural space to perform a finger sweep to assure entry is in the thoracic cavity and no lung is adherent to the thoracic wall. This step is important as the inability to pass a finger into the thoracic cavity and identify structures could indicate inappropriate anatomic loca-

tion and malposition of the chest tube if attempt is made to place it. Once this step is completed, the chest tube should be inserted through the incision and into the pleural cavity. The Kelly clamps can be used to aid in the directional placement of the chest tube. For a pneumothorax, the tube should be placed anteriorly and near the apex. For a hydrothorax, the tube should be placed posteriorly and near the lung base, as possible. The tube should then be connected to a closed drainage system or Heimlich valve [18]. For extended incisional openings, the skin should be closed with silk or monofilament suture. The tube will then need to be sutured in place as described below. Finally, a gauze dressing is placed over the chest tube. All connections between the chest tube and the water seal device should be taped to prevent accidental dislodgement. Upon completion of the procedure, a chest radiograph should be obtained to verify correct placement of the chest tube.

Seldinger

Prior to needle insertion, the operator should palpate the area of the skin mark, to identify the superior and inferior ribs, and the corresponding ICS. Next, a hollow bore needle, attached to a 10 milliliter syringe, should be inserted through the skin. Once through the skin, the operator should continuously pull back on the syringe to assure no entry into a blood vessel has been made as the needle is advanced. The needle should be advanced slowly over the inferior rib to avoid the neurovascular bundle. When air and/or fluid is aspirated, the operator should stop advancing the needle and hold into place to avoid displacing the needle backward into the subcutaneous tissue or forward into the lung parenchyma. Next, the syringe should be removed and a guidewire inserted through the hollow bore needle and gently advanced until resistance is met or approximately 20 centimeters remains outside of the patient [18]. At no point should the wire be fully inserted into the chest. Next, the hollow needle can be removed, maintaining contact with the wire to assure it does not migrate either in or out of the patient. Once the needle is secure, an 11-blade scalpel should be used to create a skin nick, opening the skin from the place of needle insertion perpendicular to the wire to assure entry of the dilator. Next, sequential dilation should be carried out with the dilators provided in the kit to dilate the subcutaneous tissues and the pleura along the guidewire. The operator should assure that each dilator is inserted only far enough to dilate the subcutaneous tissues and the parietal pleura. Over-insertion of a rigid dilator can lead to injury to the lung, great vessels, or the heart [5]. Once this is completed, the chest tube can be inserted into the pleural cavity over the guidewire. The distance of entry will depend on each patient. Every effort should be made to direct the catheter anteriorly in the case of pneumothorax and posteriorly in the case of hydrothorax. Once the chest tube is in place, the guidewire can be removed followed by connection of the tubing in the kit that allows for direct connection to a closed drainage system [18]. Finally, the tube is sutured into place as described below and covered with a gauze dressing. All connections between the chest tube and the water seal device should be taped to prevent accidental dislodgement. Upon completion of the procedure, a chest radiograph should be obtained to verify correct placement of the chest tube.

Securing the Chest Tube

The recommended suture for securing a chest tube is #0 silk suture. Once the tube is in place, a single interrupted stitch should be tied adjacent to the tube, leaving an adequate amount of suture to wrap both ends of the suture around the tube. Next, one end of the suture should be wrapped around the tube and pulled through the circle made by the suture in a manner similar to a half hitch, prior to tightening. The same should be completed with the other end of the suture. The suture should be tied down, making a small indention in the chest tube. The operator has the option to perform this a second time as deemed necessary. Please see Fig. 23.4a, b for demonstration of a horizontal mattress suture to close the wound and a similar method to secure the chest tube.

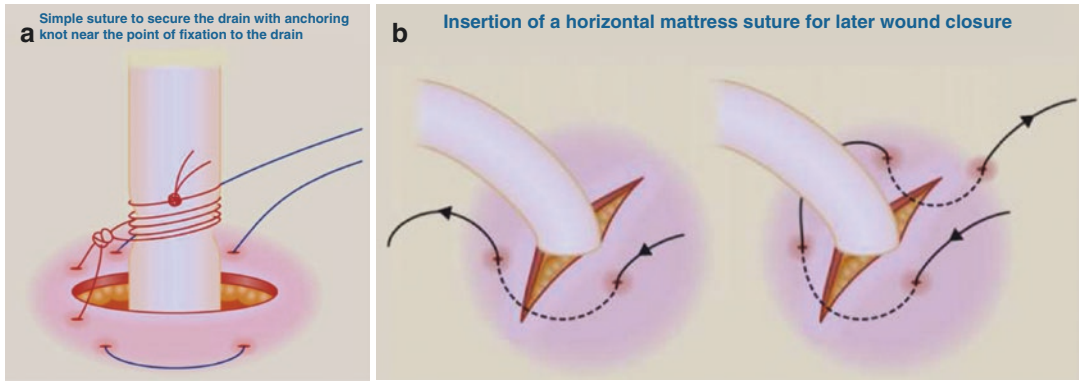

Fig. 23.4 (**a**, **b**) Suturing the chest tube in place. (Reprinted from Kirmani and Zacharias [5]. With permission from Elsevier.)

Complications

The average rate at which complications can occur is approximately 10 percent [7, 8]. Because of the invasive nature of this procedure, several different complications are possible, all of which can contribute to morbidity and mortality. The first is the development of a hemothorax, which is rare. This can occur via injury either to an intercostal blood vessel during insertion, an intrathoracic vessel, or even the heart. These etiologies, particularly the latter two, are potentially life threatening as catastrophic hemorrhage can occur and may require immediate intervention, such as a thoracotomy or sternotomy, for repair [8, 18].

The second complication is lung laceration, which can occur during insertion. Patients at particular risk include those with previous chest tube placement or previous pleurodesis as these patients will tend to have pleural adhesions [8]. For the open technique, lung injury can occur if a trocar is used to place the chest tube. It is for this reason that the use of a trocar is discouraged. For the Seldinger technique, over-insertion of the needle, depending on the size of the pneumothorax and/or hydrothorax, or the over-insertion of the dilator can lead to parenchymal injury [18]. Lung injury can lead to the development of a bronchopleural fistula, albeit rare, and/or lung abscess [8].

Another complication that may impact morbidity and mortality is the incorrect position of the chest tube. First, chest tubes can be placed in the subcutaneous tissue and can occur with either the open or Seldinger techniques. This may be more common with severely obese patients or those with multiple rib fractures [8]. If the operator does not suspect, see, or hear air and/or fluid removal after tube insertion, then a chest radiograph is necessary to determine tube position [8]. A far more concerning anatomic malposition of the chest tube is intra-abdominal placement. Again, this can occur with either technique. Of concern is placement into a hollow organ such as the small bowel or stomach, or solid organs such as the liver and spleen, which may require nonsurgical intervention with interventional radiology or surgical intervention to correct the defect from this error [8, 18].

The final complication to discuss is incidental dislodgement. Dislodgement can occur for several reasons, including improper securing of the tube and changes in patient position in the bed. Body habitus can also play a role in dislodgement [8, 18]. Obtaining a chest radiograph will be important to determine if the sentinel eye of the chest tube, representing the last hole on the chest tube closest to the thoracic wall, is outside the thoracic cavity and in the subcutaneous tissues or external to the body. Should this occur, a decision will need to be made regarding replacement of the chest tube, depending on the existing length of time the chest tube has been in place and the patient's clinical situation.

Post-Procedure Management Considerations

Drainage Systems

For the chest tube to work effectively at draining a pneumothorax and/or hydrothorax, it will need to be connected to a device that allows for one-way removal of air and/or fluid. The Heimlich valve (Fig. 23.5a) is a plastic one-way valve device that utilizes a rubber flutter valve system to allow the release of air during inspiration and will occlude during expiration (Fig. 23.5b). For patients who have a pneumothorax only, this device can be effective to evacuate the pneumothorax and can be less cumbersome for the ambulatory patient. The blue end connects directly to the chest tube. The white end can be attached to suction but is not required [8].

By far the most common method to drain air and/or fluid is a closed drainage system (CDS). The most common are commercial plastic devices such as the Atrium and Pleu-evac [8]. These systems include three separate chambers. The first is a collection chamber, which is used to collect any intrapleural fluid that is drained. The second is a water seal chamber, a chamber with a small column of water, that allows for the one-way release of air without air re-entering the pleural space. Once the chest tube is attached, it will be important to observe the water seal chamber for air bubbling, which typically indicates an air leak. Air leaks are discussed later in this chapter. It will also be important to observe the chamber for movement of the water associated with the respiratory cycle. The movement of water, described as "tiding," signals correct placement of the chest tube [8]. And, finally, the third chamber is the suction control chamber, which allows for the prescribed amount of suction to be applied by the orders of the physician and/or advanced practice provider. Depending on the brand of CDS used, suction can be ordered anywhere from −5 mmHg to −45 mmHg. Wet drainage systems require a pre-set volume of water within the chamber that will coincide with the amount of suction ordered. Dry drainage systems, on the other hand, do not have a water column but instead have a dial on the device to choose the amount of suction prescribed. Both of these CDSs can be attached to an external suction device or can be placed on "water seal," which entails the device not being attached to suction but instead relying on the water seal chamber to maintain the intact system. When not attached to suction, the system is on gravity drainage [8].

The aforementioned CDS are described as analog systems and, again, are the most commonly used. Digital systems are slowly gaining popularity, particularly in chest tube management after thoracic surgery. This device will monitor and record chest tube output and intrapleural pressure and monitor for air leak. The system will adjust the necessary suction to achieve a predetermined intrathoracic pressure.

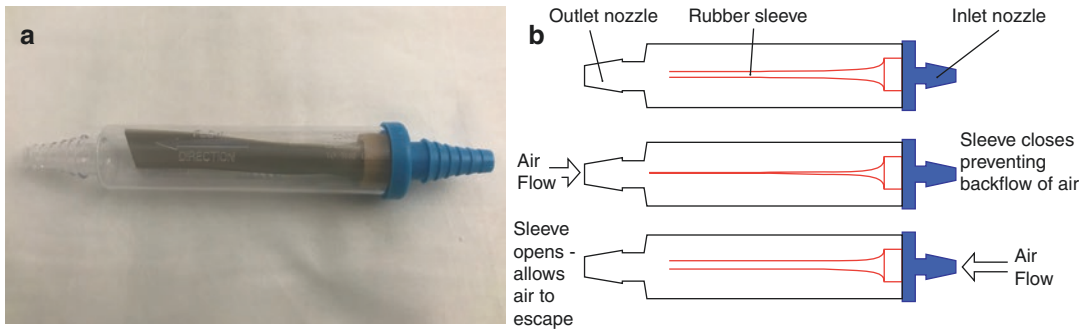

Fig. 23.5 (**a**, **b**) Heimlich valve. (**b**: Reprinted from Wikipedia. Retrieved from: https://commons.wikimedia.org/wiki/File:Heimlich_valve.GIF. With permission from Creative Commons License 3.0: https://creativecommons.org/licenses/by-sa/3.0/deed.en)

From a patient's perspective, the advantage of this device is that the patient is free to ambulate since it is not attached to an external suction device [8].

Air Leaks

Air leaks can occur from traumatic and nontraumatic causes of pneumothorax. First, a technical failure can result from partial dislodgement of the chest tube, disconnection of tubing, or an inadequate seal at the chest tube insertion site resulting from inadequate closure of the wound via suture. Absent of a technical reason, an air leak can be further classified as an alveolar pulmonary fistula (APF) or a bronchopulmonary fistula (BPF). An APF results in direct communication between the alveoli and the pleura, whereas a BPF results in communication between bronchus and the pleura. The reported incidence for BPF is variable, from 0.5 to 28 percent for pneumonectomy and 0.5 percent for lobectomy. BPF is more prevalent in malignancy, and pertinent risk factors include previous chemotherapy and radiation treatment [19].

In the traumatic injury patient, blunt trauma accounts for greater than 90 percent of chest injuries. Air leaks generally occur from direct parenchymal injury typically as a result of displaced rib fractures. Such an injury can lead to a pneumothorax and subsequent prolonged chest tube duration as well as intubation and mechanical ventilation for associated thoracic injuries [20].

An air leak may be short lived and can resolve on its own. However, an air leak persisting for greater than 5–7 days is considered a persistent air leak [19, 20]. While mild air leaks often resolve with supportive care, including chest tube placement, severe air leaks will often persist and can lead to ventilation/perfusion mismatches, particularly in intubated patient with APF or BPF as the challenge arises in maintaining positive end-expiratory pressure [20].

Cerfolio and colleagues [21] developed a classification system to assess the severity of an air leak (Box 23.3). A grade 1 leak accounts for approximately 98 percent of all leaks. It is characteristically noted only on forced expiration, or coughing. A grade 2 air leak is noted primarily on expiration and may be associated with a parenchymal injury or an APF. A grade 3 air leak occurs during inspiration and is typically associated with patients on positive pressure ventilation or a large BPF. And, finally, a grade 4 air leak is essentially a continuous air leak noted throughout the inspiratory and expiratory cycle. As with a grade 3 leak, this type of leak is commonly associated with a large BPF or patients on positive pressure ventilation. It is important to note the grade of the leak during the daily assessment as this could be a marker for progress, or the lack thereof, for the healing of a fistula [19–22].

Box 23.3 Classification System for Air Leak

Grade 1	During any forced exhalation
Grade 2	Expiratory phase only
Grade 3	Inspiratory phase only
Grade 4	Continuous bubbling during both inspiration and expiration

Based on data from Ref. [19]

Discussion of treatment for a persistent air leak, whether an APF or a BPF, is beyond the scope of this chapter. The presence of an air leak warrants close observation through serial exams and determination of the grade of leak. Should the leak not heal with supportive care and chest tube management, then the expertise of an interventional pulmonologist or cardiothoracic surgeon may be required [19]. In cases of thoracic trauma with a persistent severe air leak, early surgical intervention can improve outcomes and lead to a shorter length of stay [20].

Chest Tube Removal

Once the therapeutic endpoints for the chest tube are achieved, it can then be removed. Clinical indicators for tube removal include the placement of the CDS off suction and onto water seal, the lack of air bubbling in the water seal chamber, and a fully expanded lung on chest radiograph [8]. Indications for removal of the chest tube after a

pleural effusion relate to the etiology of the effusion [8]. For an empyema or parapneumonic effusion, a smaller drainage volume, less than 50 ml per day, may be indicated prior to removal, whereas a larger drainage volume of fluid, as high as 200 ml/day, may be allowable prior to removal of a chest tube for transudative effusions. The threshold amount of daily drainage will be determined by the physician and/or advanced practice provider, pertinent to the patient's clinical picture.

The supplies needed for chest tube removal include suture removal kit, blue pads (for fluid containment upon removal), 4 × 4 gauze, petroleum gauze, and tape. Prior to removal, prepare the 4 × 4 gauze and petroleum gauze to make an occlusive dressing for the thoracostomy site. To remove the chest tube, the dressing will need to be removed and the suture cut at the skin. The tube should then be removed at end-expiration, asking the patient to perform a Valsalva maneuver to minimize the chance for air re-entry through the chest tube tract [8]. Immediately upon chest tube removal, place the occlusive dressing over the thoracostomy site and tape the dressing in place. Obtain a chest radiograph in 2–4 hours after chest tube, or as clinically indicated, to evaluate for the presence of a pneumothorax.

Summary

1. Chest tube placement is indicated to remove air and/or fluid from the pleural space. While considerations, such as the presence of coagulopathy, should be identified, no absolute contraindications exist for placement of the chest tube.
2. Pleural ultrasound can be an effective tool for optimal placement of the chest tube in patients with a hydrothorax.
3. Post-procedure management includes pain control, use of a closed device drainage system, and the monitoring for air leaks, which is likely related to an APF or BPF, once a technical etiology is ruled out. Lower-grade leaks may result in resolution of the air leak, while severe leaks will likely result in endobronchial or surgical repair.

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Inferior Vena Cava Filter Insertion in the Critically Ill

24

Jennifer J. Marrero and A. Britton Christmas

Introduction

Venous thromboembolic events (VTE) which include pulmonary embolism (PE) and deep venous thrombosis (DVT) affect over 600,000 people in the United States and incur significant morbidity and mortality [1]. Critically ill patients are at high risk for PE and DVTs and often cannot receive chemoprophylaxis to decrease their risk nor therapeutic anticoagulation dosing if they are diagnosed with a VTE.

Inferior vena cava (IVC) filters, which have been used since the 1960s, have gained popularity with the advent of percutaneous placement and retrieval techniques. This evolution has been beneficial that patients who undergo this procedure are critically ill, requiring mechanical ventilation, invasive monitors, and/or multiple infusion pumps providing critical medications such as vasopressors. The transportation of critically ill patients throughout the hospital for procedures often proves difficult and may place the patient at risk for adverse events such as airway or pulmonary complications to include extubation, malpositioning of the endotracheal tube, or hypoxia [2]. The incidence of hemodynamic alterations or other physiological changes has been reported to be as high as 66% in ICU patients [3].

Indications

The primary indication or FDA-approved use for placing an IVC filter is to prevent the occurrence of pulmonary embolism (PE) by trapping fragmented thromboemboli from deep leg veins as they travel to the pulmonary circulation [4]. The risk factors for development of a deep vein thrombus and PE are often fluid during a patient's illness, often lessening or increasing, as their medical condition evolves. Therefore, the necessity for, duration of implantation of, and decision for removal of an IVC filter will vary among patients and should be determined by the healthcare provider.

IVC filter placement may also be indicated for patients who suffer a pulmonary thromboembolism in situations where anticoagulant therapy is contraindicated or terminated due to bleeding complications, failure of anticoagulant therapy in thromboembolic diseases, or for emergency treatment following massive PE when anticipated benefits of conventional therapy are reduced [5, 6].

Prophylactic filter use had gained in popularity due to the introduction of retrievable filters. This

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indication was not approved use by the FDA, but while studies continued to have a lack of high-quality data, overall literature had previously supported the use of prophylactic IVC filters in high-risk poly-trauma patients with contraindications to DVT prophylaxis [7]. Contraindications to anticoagulation would include trauma patients who have intracranial hemorrhage or other uncontrolled bleeding such as gastrointestinal bleeding. Complications of anticoagulation that include significant bleeding are not uncommon in elderly patients or those with chronic kidney disease [8]. Failure of anticoagulation would be defined as the inability to reach therapeutic levels or documented progression of DVT or a recurrent PE while on anticoagulation.

More recent data has shown trends toward decreased use of prophylactic filters. [9] noted that despite an increase in the rate of prophylactic filter placement, the reported incidence of PE after trauma exhibits more than a twofold increase over the past decade. Of interest, IVCF placement demonstrates only a small PE-attributable mortality decrease [10]. While it is likely that better-quality reporting databases and improved detection methods have contributed to this increase, there is not enough data to substantiate a corresponding decrease in mortality related to PE when using the prophylactic IVCF. In a large, retrospective study by Shenoy et al., prophylactic filters were not shown to confer a benefit to patients and did not decrease the incidence of PE in high-risk patients [11]. Also, an additional study by Ho et al. found that when the cost and risks of IVC filters are calculated, there is no urgency for prophylactic placement of IVC filter in patients who can be treated with prophylactic anticoagulation within 7 days of injury [12].

Temporary filters are another option for IVC filters that are designed for short-term use only. The only one approved for use in the United States is the Angel Catheter (Bio2 Medical, Golden [CO]) which is a device that is a temporary filter and central venous catheter combination, consisting of a self-expanding nitinol IVC filter attached to a 9-French triple-lumen central venous catheter that is inserted via the femoral vein and sutured to the skin [13]. A very small pilot study by Cadavid et al. found no initial safety or efficacy concerns for use of the Angel Catheter for short-term protection from PE [14]. A larger European study showed similar safety and efficacy with the Angel Catheter, deeming it to be a valid alternative for short-term PE prophylaxis for high-risk patients with contraindication for anticoagulation [15]. The additional benefit of this temporary ICVF catheter is the ability to be performed as a bedside procedure in the critically ill patient.

Contraindications

Absolute contraindications to vena cava filter placement is the inability to gain vascular access to the vena cava or anatomical anomalies, such as cava size greater than 30 mm, that would preclude placement. Severe coagulopathy and bacteremia are relative contraindications [16] and should be considered while assessing the patient's overall clinical picture, risk, and benefit.

Preparation

Bedside insertion of IVC filters using portable C-arm equipment with ionizing radiation or ultrasound provides a safe option for critically ill patients in the ICU. With proper education and proctoring, this also enables other specialists such as critical care medicine intensivists and trauma surgeons to provide this service to their patients in a safe and timely manner.

Bedside fluoroscopic procedures can be safe despite radiation concerns. A paper by Mostafa et al. in 2002, demonstrated that despite multiple radiographic studies within an ICU, radiation exposure was not a significant hazard due to minimal exposure time and distance of at least 3 meters from the patient [17]. Of note, it is of utmost importance that those involved in any radiologic bedside procedure wear protective lead aprons.

Pre-insertion imaging is critical as it ensures patency of the vena cava, provides the ability to measure the size of the vena cava, depicts any

unsuspected anatomic anomalies, and delineates the location of the renal veins. The filter, when properly placed most caudal to the renal veins, is usually deployed at approximately the L3 position [18].

A few options exist for pre-insertion imaging. Traditionally iodinated contrast has been the gold standard for imaging the cava. However, these agents have established risks of allergic reaction, nephrotoxicity, and subsequent renal failure, particularly in patients who are at high risk for renal complications [19]. Carbon dioxide-contrasted pre-insertion cavogram produces excellent opacification of the IVC and demonstrates locations of both the renal veins and the iliac bifurcation [20], although this contrast medium does require digital subtraction which may be performed by most portable C-arm equipment. As such, carbon dioxide cavography is a safe and highly effective alternative for patients with an overall similar cost to iodinated contrast [21].

Intravascular ultrasound (IVUS) and transabdominal duplex ultrasound are other options to delineate caval anatomy for filter placement. IVUS allows for direct intraluminal visualization of the vena cava and the renal veins [22] (Fig. 24.1). There is approximately a 2–12% rate of placement failure or misplacement which may occur due to the inability to identify all anomalies of the cava that could potentially impact placement [23–25]. Bedside IVC filter placement guided by these techniques has been reported as safe, effective, and reliable particularly while using the femoral approach [26]. While not the gold standard, this technique does offer other an additional option for the critically patients who are difficult to transport.

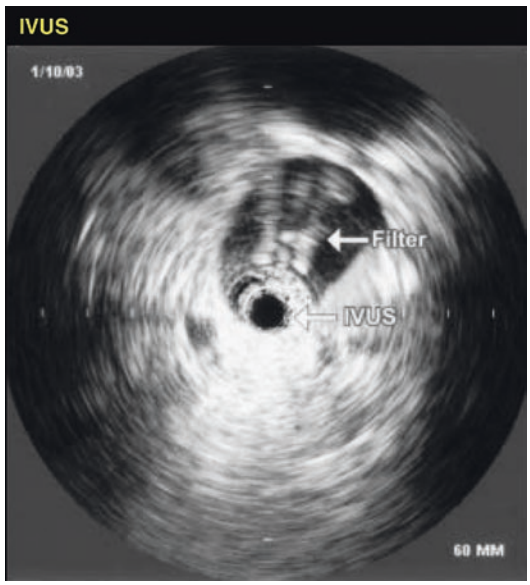

Fig. 24.1 IVUS

Procedure

Insertion of IVC filters can occur at the bedside in the intensive care unit (ICU), in the angiography suite, or in the operating room (OR). This paper will specifically review the procedure for bedside insertion of the IVC filter.

Proper informed consent should occur which includes a thorough review of the procedure's benefits and risks with the patient or their surrogate decision-maker. It is important to review the patient's laboratory values such as the coagulation markers including international normalized ratio and prothrombin time and the patient's renal function. While elevated coagulation markers do not preclude placement, it does indicate patient's potential to incur complications such as bleeding at puncture site or hematoma development. Renal function must be assessed as the use of contrast for IVC filter placement may be nephrotoxic especially in the already injured kidney. If patient's renal function is insufficient to tolerate iodinated contrast, then CO2 contrast may be necessary for placement.

Gather necessary equipment for procedure. Please see Table 24.1 for a comprehensive list. Portable fluoroscopy is used for this bedside procedure (Fig. 24.2). Prior to obtaining vascular access, all catheters, dilators, and wires are flushed with heparinized saline (2 units of unfractionated heparin per 1 ml of normal saline solution) or plain saline. It is important to keep catheters flushed so air is not injected during the procedure. Also, take care to avoid the formation of clots within the catheters as these may be inadvertently injected during the procedure.

Table 24.1 Supplies for bedside IVC filter placement

Supplies for bedside IVC filter placement	
C-arm	150 cc injector syringe
Lead aprons	72-inch pressure tubing
Med-Rad pressure injector	5 Fr pig-cava angiography catheter
Radiographic contrast	Three-way stop-cock
Sterile gown gloves	145 cm 0.035 "J"-tipped guide wire
Central venous access line kit	Vena cava filter of choice

Fig. 24.2 C-arm in place for procedure

Insertion site is sterilely prepped and draped. Vascular access is obtained most commonly via the right femoral vein, although using the right internal jugular may be necessary in some cases. There are some filters such as the Option Elite (Argon Medical, [TX]) that provide ability to use a femoral or jugular approach with cartridges that are clearly marked to assist with assembly orientation [27] (Figs. 24.3, 24.4, and 24.5). The use of ultrasound to identify and confirm vessel anatomy can be utilized. The dilator and the introduction catheter are inserted under fluoroscopy and confirmed with contrast using a contrast injector. Once vascular access is obtained, using the Seldinger technique, a 145-cm-long, 0.035-inch diameter J-tipped guidewire is advanced into the vena cava. A small skin stab wound is performed with a number 11 scalpel to facilitate for the passage of subsequent catheters. An injection pigtail catheter (Fig. 24.6) is then inserted to the level of the interspace between the fourth and fifth lumbar vertebral bodies when using femoral

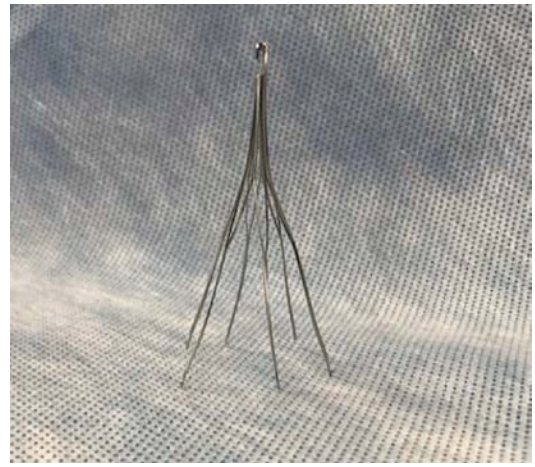

Fig. 24.3 Option Elite retrievable vena cava filter (Argon Medical Device [TX])

Fig. 24.4 Jugular approach cartridge

approach. Several filter kits now include injection dilators in combination with the insertion sheath. A contrast venogram should be performed using a total of 30 ml of non-ionic iodinated contrast

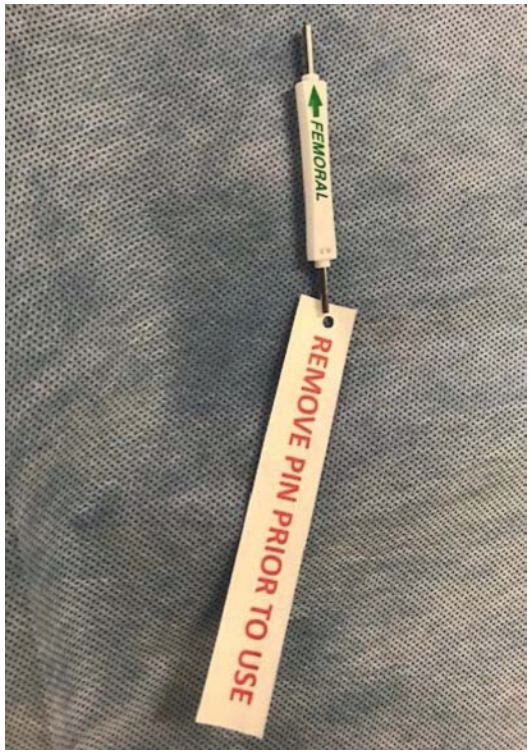

Fig. 24.5 Femoral approach cartridge

Fig. 24.6 Pigtail catheter connected for contrast

medium and is injected over a 2 second time interval (Fig. 24.7). The guidewire is then replaced, and the pigtail catheter is subsequently removed.

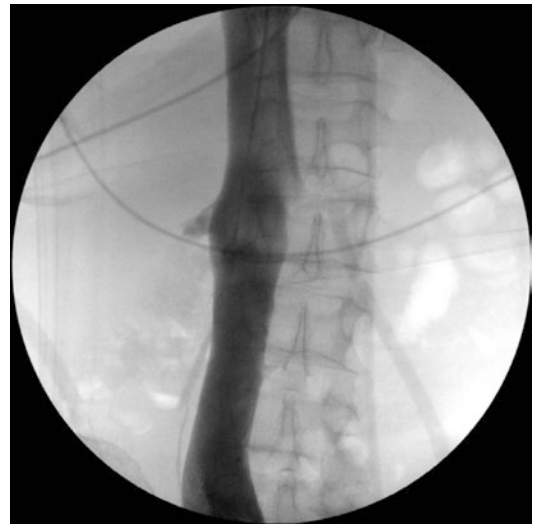

Fig. 24.7 Pre-insertion cavagram

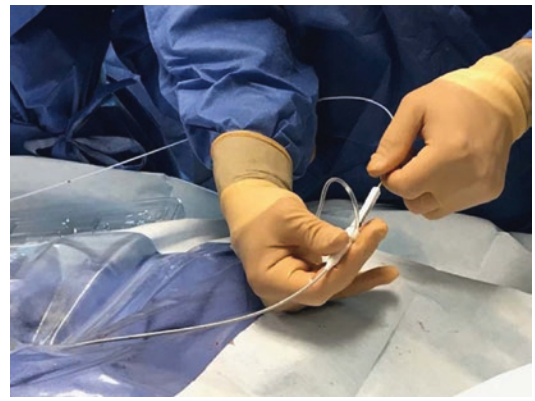

Fig. 24.8 Filter being advanced

Next the dilator and introducer sheath for the VCF is advanced to the infrarenal position. All catheter manipulations should be performed under fluoroscopic visualization over the guidewire. The VCF is inserted (see Fig. 24.8) and deployed in the infrarenal position. This is confirmed by a post-placement venocavagram which consists of 30 ml of non-ionic iodinated contrast injected over a 2 second time interval (Fig. 24.9). The sheath is removed, and pressure is held to the access site for 5 minutes [28].

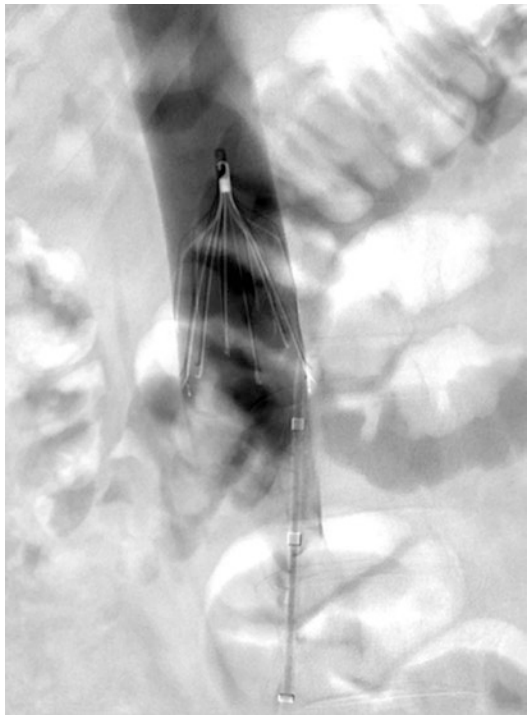

Fig. 24.9 Post-insertion cavagram

Complications

As with any procedure, IVC filters may pose complications related to placement. It is imperative that any catheter-advancing manipulations are over-performed over the guidewire. Immediate complications are rare but include pneumothorax (with right internal jugular approach), insertion site hematoma or thrombosis, filter migration, or vena cava thrombosis with rates identified anywhere from 0% to 35% [29]. Other potential complications include IVC wall perforation and filter fracture. Of note, the incidence of fractures is reported as 0–1.9% in the newer filters [30].

Despite the increased use of IVC filters, the removal rates are extremely low. One systematic review reported a retrieval rate as low as 34% [31]. The long-term complications from retrievable IVC filters over a prolonged time have not been studied well to date. Low retrieval rates are likely related to loss of patients in follow-up or patient noncompliance [32]. The US Federal Food and Drug Administration (FDA) issued an alert that retrievable IVC filters should be removed once risk of PE has resolved which, for most cases, represents a timeframe of approximately 29–54 days after insertion [33]. Although most filters should be retrieved when they are no longer indicated, they should still be reviewed on a case by case basis to evaluate for removal. Dedicated databases and processes to review patients for follow-up could increase compliance and improve retrieval rates.

CPT Coding

- CPT 37191: *Insertion* of intravascular vena cava filter, endovascular approach including vascular access, vessel selection, and radiological supervision and interpretation, intraprocedural roadmapping, and imaging guidance (ultrasound and fluoroscopy), when performed
- CPT 37192: *Repositioning* of intravascular vena cava filter, endovascular approach including vascular access, vessel selection, and radiological supervision and interpretation, intraprocedural roadmapping, and imaging guidance (ultrasound and fluoroscopy), when performed (do not report 37192 in conjunction with 37191)
- CPT 37193: *Retrieval* (removal) of intravascular vena cava filter, endovascular approach including vascular access, vessel selection, and radiological supervision and interpretation, intraprocedural roadmapping, and imaging guidance (ultrasound and fluoroscopy), when performed (do not report 37193 in conjunction with 37197)

Summary

While anticoagulation remains the well-established treatment for PE and VTE, IVC filters still have indications for use in certain patient populations in the presence of bleeding complications or in situations on which anticoagulation is not tolerated. The introduction of temporary

catheters offers a potential alternative for these patients, and the hope is that there will be more robust evidence for these devices in the future. Due to the complications and often difficulty in follow-up for removal, it is necessary for a provider to fully assess the risks and benefits regarding the placement of these devices.

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Part V

Neurological Procedures

External Ventricular Drain Placement

25

Lauren Dobay Voeller, Asha Avirachen, and David K. Kung

Introduction

Anatomy

The human ventricular system consists of four CSF-filled chambers that are normally in communication with each other. The chambers are designated as lateral ventricle [1], third ventricle, and fourth ventricle. Each lateral ventricle is divided into the frontal horn (anterior), body, atrium, occipital horn (posterior), and temporal horn (inferior) [2].

New bulk CSF flows from the two lateral ventricles located in the two cerebral hemispheres into the third ventricle through the foramen of Monro. Through the cerebral aqueduct of Sylvius, CSF flows from the third ventricle to the fourth ventricle located in the brain stem. From the fourth ventricle, CSF flows through the foramen of Magendie medially into the central canal and through foramen of Luschka laterally into the subarachnoid space. Passing through the foramen of Magendie results in filling of the cranial and spinal subarachnoid space [2].

The CSF from the subarachnoid space is eventually reabsorbed mainly through outpouchings, called arachnoid villi, into the superior sagittal sinus and restored back into blood circulation.

CSF production is a complex process regulated by the highly vascular and specialized choroid plexus. The choroid plexus is a group of ependymal cells lining the ventricles and responsible for CSF production. Approximately 10–30% of CSF arises from the movement of interstitial fluid from the brain parenchyma. CSF is produced at a rate of about 20–25 ml/hour averaging approximately 500 ml each day. In an average adult human, there is roughly 100–140 ml of CSF at any given time. Normal CSF pressure is 6–18 cm of water or 5–15 mm of Hg. The purpose of CSF is to act as a shock absorber, cushioning the brain and spinal cord against injury caused by movements. In addition, CSF allows movement of metabolites and plays a role in hormonal and signaling mechanisms [2].

Indications

Common Scenarios Where EVD is Indicated [2, 3]

- Subarachnoid hemorrhage (SAH)
- Intraventricular hemorrhage (IVH)
- Obstructive hydrocephalus

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- Infectious meningitis (causing recalcitrant ICP elevation)
- Carcinomatous meningitis (causing recalcitrant ICP elevation)
- Traumatic brain injury with GCS < 8
- Conditions requiring short-term intraventricular drug infusion

Contraindications

Potential Contraindications for EVD

- Patient receiving anticoagulation therapy
- Patient has a disturbance in coagulation or platelet dysfunction
- Significant posterior fossa mass effect

The contraindications to placing an EVD are relative in that most are reversible and/or depend on the severity of the situation. Risks and benefits should be considered, and if the patient has one of the above contraindications, appropriate reversal measures should be taken if possible [1, 2].

Coagulation labs should be done to quickly diagnose coagulopathy, and institutional practice guidelines should be followed to correct any coagulopathies prior to EVD placement. A thorough medication reconciliation should be performed, and any anticoagulant and antithrombotic use should be confirmed [2].

Platelet transfusion prior to EVD insertion regardless of platelet count should be considered for patients taking antiplatelet therapy such as Aspirin or Plavix. Platelets should also be transfused in patients with platelet counts <100,000 [2].

Risk/Benefits

Common risks associated with EVD placement include hemorrhage and/or infection. Some common benefits include reduction in ICP and diversion of blood and CSF. When used appropriately, the use of an EVD is usually a life-saving intervention [3].

Preparation

- Review the indications for the procedure.
- Labs should be reviewed with close attention to coagulation. An INR <1.4, PTT 40 or less, platelets >100,000 should be confirmed prior to placement.
- A recent CT or MRI scan should be done prior to EVD insertion to ease decision-making on the entry and trajectory of EVD catheter.
- Obtain consent from the patient or legal representative; however emergency placement is also acceptable.
- The patient should be positioned supine with the head of bed at 30–45 degrees and the head positioned in a neutral position. Ensure comfortable bed height for the provider performing the procedure.
- Administer a single dose of broad spectrum antibiotics such as cefazolin or vancomycin if the patient has a penicillin allergy, in accordance with institutional protocol.
- Administer conscious sedation or perform intubation as clinically appropriate.
- Ensure proper invasive and noninvasive monitoring is available throughout the procedure.

Supplies

- Sterile gloves, gown, mask, hat
- Sterile drapes
- Sterile surgical marker
- Electric clipper
- Antimicrobial solution (i.e., povidone-iodine)
- Intracranial access kit
- Ventricular catheter
- Ventricular drainage collection system
- Sterile flushless transducer

Procedure [2, 4]

1. Position the patient for EVD insertion: place the head of the bed at 30–45 degrees; ensure the head is in a neutral position and immobilized for the procedure.

2. Don personal protective equipment and ensure all staff in proximity have appropriate gear.
3. Perform a timeout per institutional protocol.
4. Prepare the insertion site:
   - Usually the patient's non-dominant hemisphere is preferred; in the majority of the population, this is accessed through the right frontal scalp.
   - Clip hair over an area adequate to place the EVD and clean the scalp using antiseptic solution.
   - Mark Kocher's point: use a surgical pen to mark 11 cm behind the nasion and in the mid-pupillary line (located 3 cm lateral to the midline of the skull).
   - Using sterile towels, drape the surrounding areas.
5. Inject lidocaine into the scalp at the point of entry. Local anesthetic can also be injected at the planned exit site of the tunneled catheter.
6. Using a scalpel, make a 1–2 cm linear incision down to the skull.
7. Place retractors at the incision site to hold the skin back.
8. Drill a hole through the skull. Ideal trajectory will be in a plane perpendicular to the skull. Take great care not to plunge the drill into the brain and cause hemorrhage. Stop turning the drill bit, when there is complete loss of resistance, which confirms the exit from the inner table. Remove the drill and clear any bone chips with sterile saline. Use bone wax if heavy bleeding is encountered.
9. Irrigate burr hole with sterile saline.
10. Make a small puncture in the dura using an 18 gauge spinal needle. Using the tip of needle, enlarge the hole in a cruciate fashion until it is just large enough to pass the catheter.
11. Slowly insert the EVD catheter perpendicular to the skull through the burr hole to a max depth of 6 cm from the outer skull table. CSF is usually encountered at 4–5 cm. Catheter is aimed at the ipsilateral medial canthus of the eye and tragus of the ear.
12. Ensure CSF flow by removing the stylet. Keep the tip of the catheter clamped to prevent overdrainage.
13. Utilizing the metal trocar provided in the cranial access kit, tunnel the catheter under the galea approximately 3–4 cm away from the original incision. The catheter is then tunneled and secured. Remove trocar and confirm catheter is still draining CSF.
14. Place the Luer-Lock on the ventriculostomy catheter to prevent overdrainage.
15. Close the incision with 3-0 nylon, ensuring not to puncture the catheter.
16. After skin closure, secure the catheter tight to the scalp in at least three separate locations with staples or sutures to protect it from being pulled out. Make sure sutures are not too tight as to impede the flow. Clean the area with povidone-iodine or chlorhexidine and apply the dressing per institutional policy.
17. Remove the Luer-Lock and attach the distal end of the ventricular catheter to the drainage system once it is completely primed. Establish appropriate flow of CSF into the drip chamber.
18. Level the drainage system to the patient's tragus, which corresponds to foramen of Monro. Determine the appropriate drainage level based on the pathology and treatment plan.
19. Ensure accurate placement of the catheter with a CT head without delay. Ideal placement will be catheter tip in the anterior horn of the lateral ventricle.

Alternate Insertion Points

While Kocher's point is the most commonly used point of entry for EVD insertion, there are other methods which will be briefly discussed below. Kocher's point remains the most widely accepted approach to do a ventriculostomy at bedside [5].

1. Keen's point: Burr hole is placed 2.5–3 cm superior and 2.5–3 cm posterior to the superior point of the pinna. The catheter is placed

perpendicular to the skull with the tip entering the trigone of the lateral ventricle [2].
2. Frazier's point: Burr hole is placed 4 cm lateral to the midline and 6 cm above the inion. The catheter is placed perpendicular to the skull toward the glabella. This is frequently used in posterior fossa surgery [2].
3. Dandy's point: Burr hole is placed 2 cm lateral to the midline and 3 cm above the inion. The catheter is placed perpendicular to the skull [2].
4. Orbital point: A large bore spinal needle is placed through the anterior third of the orbital roof after elevating the lid and pressure is placed on the globe. A needle is placed 1–2 cm behind the orbital rim toward the coronal suture at the midline.
5. Supraorbital point: Burr hole is placed 4 cm above the orbital rim in the plane of the pupil. It is directed midline, posteriorly, and 3 cm above the inion.

Complications

An obvious acute risk is a resultant hemorrhage such as subdural hematoma (SDH), epidural hematoma, or intraparenchymal hematoma occurring immediately after EVD insertion. A CT scan performed post placement of the EVD may reveal hemorrhagic complications such as hemorrhage along the catheter tract, intraparenchymal hematoma, or SDH. Recent meta-analysis found the rate of hemorrhagic complication after ventriculostomy placement about 7%. The rate of clinically significant hemorrhage was 0.8%. Patients with cerebrovascular disease were noted to be at higher risk for hemorrhagic complications. Age was not established as an independent risk factor. Increased hemorrhagic complications are reported in aneurysmal SAH patients undergoing endovascular treatments requiring anticoagulation (44%) than those undergoing clipping (13%). This may be attributed to the use of heparin along with antiplatelet agents like aspirin, clopidogrel, and glycoprotein IIb/IIIa receptor antagonists. If small punctuate hematoma is noted in initial scan post placement, serial CT scans as per institutional policy should be performed to ascertain the radiographic stability. Subdural hematomas or hygromas can be developed as a complication to overdrainage of CSF via EVD, which should be treated by adjusting EVD levels to minimize drainage [1].

Factors determining the incidence of hemorrhage after EVD placement depends on coagulation status, the use of platelet infusion for patients treated with antiplatelet agents, access site, drill bit size, thread distance, aggressive drilling, use of saline to irrigate the twist drill hole, removal of all bone fragments prior to dural opening, sharp or blunt dural penetration, sharp or blunt pial opening, slow or quick access of the frontal horn, removal of the stylet at ventricular entry or after advancement to the foramen of Monro, and even tightness of scalp closure.

EVD-associated infections like meningitis or ventriculitis are the most common complications, significantly affecting morbidity and mortality. Risk factors include concomitant systemic infections, depressed skull fractures, non-adherence to rigid insertion and maintenance protocols, leakage of cerebrospinal fluid (CSF) at catheter site, frequent CSF sampling and frequent EVD manipulation, and duration of EVD. Prophylactic antibiotics remain controversial due to the risk of developing resistant organisms. Periprocedural prophylactic administration of a single broad-spectrum antibiotic agent to cover common skin flora, ideally 30 minutes prior to skin incision, has been a widely accepted practice for patients undergoing placement of external ventricular drains. Antibiotic-impregnated catheters appear to be effective in preventing infections but come with a higher cost [1, 5].

The most frequent microbe is coagulase-negative *Staphylococcus* in early infection after EVD placement, while Gram-negative rods may become more prominent with longer EVD durations. The standard treatment for CSF infections due to EVD is changing the drainage system and treatment with antibiotic agents. Prolonged antimicrobial prophylaxis for the duration of the external ventricular drain is of uncertain benefit

and not recommended. Strategies that may help reduce the incidence of infection are the use of aseptic insertion techniques, limiting manipulation of EVD and CSF sampling and discontinuing EVD at the earliest [5].

An accurate position of ventricular catheter is in the frontal horn of the ipsilateral lateral ventricle anterior to the foramen of Monro or into the top of the third ventricle. Malposition of the catheter is fairly common, where the catheter either misses the ventricle or is inserted too far into the ventricle. Post-procedure head CT scans are not routinely completed in all institutions but can be useful in confirming the correct position of the catheter and can be used as a guide for the provider for readjustment or catheter exchange if necessary.

Iatrogenic vascular injury such as arteriovenous fistula and cerebral pseudoaneurysm have been rarely reported in literature. Obstruction of the catheter can happen with a blood clot or cerebral tissue [1].

Keys to Success, Perils, and Pitfalls

Key Points to Remember

- Hold the drill perpendicular to the skull to prevent slipping of drill.
- Careful not to apply excess pressure to the drill to avoid unintentionally drilling too deep and puncturing the dura.
- Avoid passing the catheter and wire stylet with dura intact, as it may cause dural stripping resulting in epidural hematoma.
- The most common mistake is making the entry point too anterior or too lateral. Marking Kocher's point with pen on scalp is very helpful before landmarks are covered by drapes. An EKG lead can also be placed at the nasion, which can be palpated through drapes.
- Air lock in the catheter lumen can prevent CSF from flowing immediately after catheter insertion. This can be resolved by gently irrigating catheter with small quantity of saline and then lowering distal end of catheter in order to siphon ventricular CSF.
- If there is no CSF flow by 6 cm depth, gently remove the catheter. Flush the catheter with sterile saline to remove debris. Reassess the landmarks and trajectory and attempt again. Avoid the tendency to insert the catheter beyond 6 cm.
- Avoid making more than two passes without CSF return. If there is no CSF return after the second pass, secure catheter in place and get a CT scan immediately to assess placement.

CPT Coding

The code for placement of a ventriculostomy through a burr hole is 61210; if done using a twist drill, code is 61107.

Summary

The placement of an EVD is a common procedure in neurocritical care and neurosurgery patients. In patients with suspected elevated intracranial pressure, CSF can be drained, and pressures can be measured with an EVD. Though complications associated with EVD placement can occasionally turn severe (hemorrhage and infection), the procedure is most often life saving in critically ill neurological patients.

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Intraparenchymal Fiber-Optic Intracranial Pressure Monitoring

26

Kevin Lewis and Jessica Jurkovich

Introduction

Intraparenchymal monitors (IPM) are an important tool used to treat critically ill neurosurgical and neurological patients who are at risk of increased intracranial pressures (ICP) [1, 2]. Since its first use in the early 1950s, ICP monitors have evolved from U-tube manometry devices into the fiber-optic monitors we use today [2–5]. Fiber-optic IPM are the most commonly used ICP measurement devices when drainage of cerebral spinal fluid (CSF) is deemed unsafe or unnecessary. They are safe, minimally invasive, and reliable in daily practice [2, 6, 7].

Patients such as those who have suffered traumatic brain injuries and anoxic brain injuries are susceptible to secondary neurologic injury related to increased ICP [2, 3, 5, 8]. Often these patients have altered consciousness that preclude the provider from being able to use the patient's exam as an indicator of worsening neurological status from increasing ICP [1, 3]. Placement allows the care team to monitor ICP in addition to brain tissue oxygenation, cerebral blood flow, and cerebral microdialysis, depending on the type of intracranial monitoring device used. Due to the short period of time between increased ICP and secondary injury, these devices are often placed urgently at the patient's bedside. With increasing demands on neurosurgical services and work hour restrictions on medical residents, advanced practice providers are optimally positioned to efficiently and safely perform the procedure [9, 10].

Indications

Despite the lack of strong evidence, current practice supports the consideration of IPM placement in the neurologically injured patient population below:

- Neurological injury deemed salvageable with a Glasgow Coma Scale of 8 or less with brain imaging that demonstrates contusions, hematomas, edema, herniation, or compressed basal cisterns [6, 11, 12]
- Traumatic injuries requiring urgent surgical repair
- Surgical patients who cannot be appropriately monitored neurologically due to anesthesia and neuromuscular blockade [1]
- Prolonged neuromuscular blockade to treat hypoxia or shivering refractory to other treatment modalities
- Monitoring of intracranial pressures in hydrocephalus patients with concern for shunt failure [13]

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Contraindications

There are few relative contraindications to placement of an IPM. The most common would be coagulopathies [6]. If these are responsive to corrective measures, such as transfusion with blood products or reversal agents, and with careful consideration to the underlying etiology of coagulopathy, then an IPM can be safely placed [14]. Absolute contraindications would include known intracranial infection, immunosuppression, and non-salvageable injuries [6].

Risks/Benefit

Although the procedure itself is relatively straightforward, it is not without risks. Infection, hemorrhage, dislodgement of the monitor, device failure, and zero drift are possible outcomes [2–5, 14]. Infection and hemorrhage are the two most common complications associated with IPM [5]. While the infection rate is much lower than in external ventricular drain (EVD) insertion, ranging from 0% to 1.7%, it is still a potential complication [5, 14]. Most infections, however, are related to insertion site and are superficial [6, 8]. More serious complication of intracranial abscess is extremely rare but can result if the conditions are right. Conditions such as reinsertion of an ICP monitor through the same site as a previously discontinued device, prolonged high dose steroids, and placement under suboptimal conditions may increase the risk of more serious infection [8]. The occurrence of hemorrhage for intraparenchymal monitors is about 4%, with underlying coagulopathy increasing this likelihood [5, 14, 15]. Although IPM placement has a lower rate of malpositioning than EVD placement, it can still be suboptimally positioned with incorrect technique [16]. Due to the fragile nature of the fiber-optic devices, they are susceptible to dislodgment and fracture during routine nursing care and are susceptible to spontaneous failure. Finally, zero drift may occur several days after insertion. Intraparenchymal monitors are zeroed once to atmospheric pressure, prior to insertion. Once the monitor is in place, the ability to recalibrate zero is lost [2, 14]. These technical complications may cause the device to be prematurely removed and require the patient to undergo an additional procedure to place a new IPM.

Preparation

Considerations/Preparation Prior to Placement

Prior to placement of any ICP monitor, a CT scan of the head should be performed to evaluate for infection or changes in the patient's anatomy due to trauma, edema, or masses. This allows the provider to choose the ideal location for insertion or rule out potential contraindications to placement [14]. Coagulation studies should be available with international normalized ratio being less than 1.3–1.6, prothrombin time less than 35, and platelets greater than 100,000 [12, 17, 18]. Patient history of aspirin, anti-platelet use, and liver disease may lead to a qualitative platelet dysfunction as well. Although normalized coagulation is ideal before any procedure, trauma patients often have coagulopathies that may be difficult to correct quickly. Some literature has demonstrated that mildly elevated coagulation markers do not significantly elevate the risk of intracranial hemorrhage related to IPM insertion. Holding placement of IPM while waiting to correct borderline coagulopathies may delay correction of intracranial hypertension and negatively impact patient outcomes [12, 17] (Table 26.1).

Table 26.1 Considerations prior to bolt placement

CT or MRI of the brain
Anticoagulant or antiplatelet use
PT and INR
Immunosuppression status
Liver disease
Living will or advanced directive

Personnel

At this time you will want to engage your medical and nursing staff to assist with positioning, gathering of equipment, and pre-medication as indicated.

Equipment

For supplies, it can help to organize your materials into sterile and non-sterile groups.

- First, you will need non-sterile supplies for skin prep and positioning:
  - Gloves
  - Waterproof pad
  - Towels
  - Hair clippers
  - Skin prep
  - Paper ruler
  - Skin marker
- Sterile supplies
  - Sterile personal protective equipment (PPE): sterile gloves, face mask, eye protection, sterile gown
  - Intracranial access kit, ICP probe kit, and any additional intracranial monitoring devices that you may be placing
  - Depending on the cranial access kit in use, the following may need to be obtained:
    - 2% lidocaine, 10 cc sterile syringe, 18 or 20 gauge needle for aspirating lidocaine, and 25 or 27 gauge needle for injecting lidocaine
    - Fenestrated drape, sterile towels, and full sterile drape
    - Sterile skin prep such as chlorhexidine
    - 3–0 nylon sutures
  - Tunneling device

Patient Positioning

Place the patient in a supine position. Ensure the bed is at a comfortable height for the proceduralist and there is adequate lighting and room for the supplies.

Anesthesia/Sedation

Adequate analgesia and sedation are needed to prevent pain and discomfort and to prevent ICP increases from stimulation. Most traumatic brain injury patients may need sedation; however analgesia would be appropriate to prevent ICP increases related to noxious stimulation. Other patients who undergo IPM placement for reasons such as hydrocephalous will require sedation to prevent discomfort and movement during the procedure. Typically propofol is used due to the anesthetic and amnestic properties, as well as its quick onset and clearance. To achieve moderate sedation, patients can be loaded with 0.5–1 mg/kg intravenously (IV) of propofol, followed by 0.25–0.5 mg IV every 1–3 minutes afterward. The primary concerns with dosing propofol are respiratory distress and hypotension. The transient hypotension can be countered using boluses of phenylephrine, 50–100 mcg IV every 10–15 minutes as needed. Respiratory depression can be addressed with supplemental oxygenation and airway positioning, with low threshold to intubate if indicated.

Fentanyl is an excellent choice for analgesia as it has a quick onset of 2–3 minutes and short duration (30–60 minutes). It does not have any amnestic effects nor does it induce hypotension when used alone. Dosing for moderate sedation begin at 0.5–1 mcg/kg IV every 2 minutes, with a maximum total dose of 5 mcg/kg IV. Respiratory depression is the main concern when administering fentanyl. Caution should be taken when administering to elderly or renal impaired patients. Naloxone 0.4–2 mg IV can be administered to reverse opioid effects, with additional doses given every 2–3 minutes as needed to stabilize the patient's respiratory status.

Midazolam is an alternative to propofol, but it is used more often for minimal sedation and as an anxiolytic. Like propofol, it has amnestic effects and is not an analgesic. It is an excellent anxiolytic with fast onset of 2–5 minutes, requiring 30–60 minutes to clear. It may be given 0.5–1 mg IV every 1–2 minutes until goal level of consciousness is reached. The concern with using midazolam is the accumulation in adipose tissue

and the lengthy time to clear. Although it may not cause hypotension alone, it is often used in conjunction with fentanyl that increases the probability of inducing hypotension.

Procedure

The insertion of IPM involves surgically placing a fiber-optic probe into the patient's parenchyma through a burr hole drilled into the skull. This is done much like an EVD but with a different trajectory for the probe and slightly different landmarks for the burr hole. The monitor is then placed through a subdural screw that minimizes the chances of the fragile probe becoming manipulated or dislodged. This screw has a vague resemblance to a bolt, hence the common vernacular term used by neurological staff, "bolt."

As with any invasive procedure, informed consent should be obtained if possible. Patients who present with altered consciousness and no next of kin available can complicate this. In these situations, emergent or administrative consent should be obtained (Table 26.2).

For any IPM placement, you will follow the same procedure for placing a burr hole.

1. Elevate the head of bed to 30° and adjust height of bed to a comfortable level.
2. Support patient head in midline position with rolled towels.
3. Cleanse work area with available materials.
4. Don mask and cap; ensure that all staff remaining in room do so as well.
5. Open and lay out cranial access kit and any monitors to be used:
   (a) It is helpful to open these kits in the order that you will be using them.
6. With clippers, remove hair along the area of scalp that IPM is to be placed.
7. Using skin marker and measuring tape, measure and mark off insertion point. It is helpful to indent the final insertion point with the marker tip as the skin prep will likely remove your markings:
   (a) Measure approximately 10–11 cm midline from the nasion, palpating for the coronal suture.
   (b) Mark approximately 1–2 cm anterior of coronal suture, to avoid motor strip.
   (c) Measure 2–3 cm lateral to either right or left, ideally to the non-dominant hemisphere unless imaging or injury dictates otherwise (Fig. 26.1).
   (d) Press skin marker cap firmly against scalp at final insertion point (Figs. 26.2 and 26.3).
8. Prep skin with antiseptic solution three times, allowing solution to dry thoroughly each time.
9. Don sterile surgical gown and gloves.
10. Apply sterile towels and fenestrated drape to scalp (Fig. 26.4).
11. Inject 1% lidocaine subcutaneously throughout incision site.

Table 26.2 Supplies for IPM placement

Non-sterile supplies	Sterile supplies
Non-sterile gloves	Surgical gloves and gown
Hair cover and mask	Cranial access kit
Waterproof pad	Monitors to be placed
Skin marker and paper ruler	Sterile drapes and towels
Hair clippers	Tunneling device (if tunneling IPM)
Towels for head positioning	3–0 nylon sutures

Fig. 26.1 Shows the use of skin marker and paper tape to measure landmarks

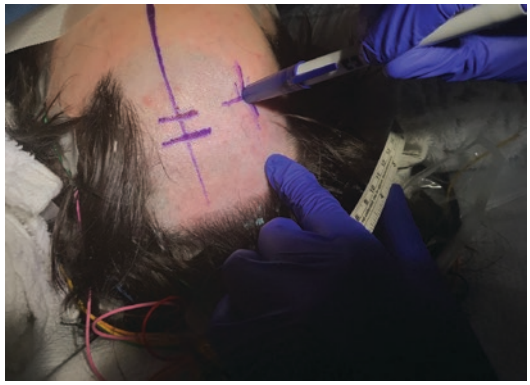

Fig. 26.2 Demonstrates using the marker to create an indent into the patient's scalp as an additional visual aid

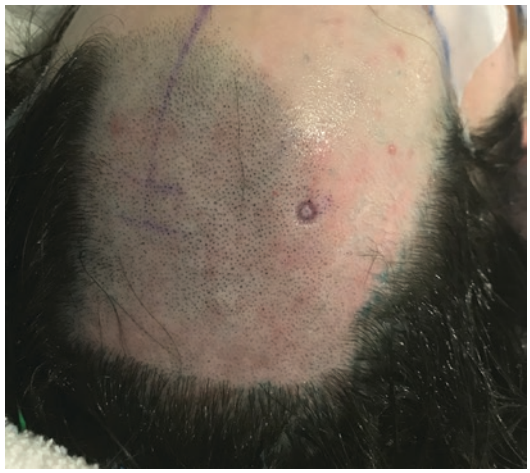

Fig. 26.3 Illustrates how marker may be washed off by skin prep and how marker indent remains as a landmark

12. Incise scalp with 11 blade approximately 1–3 cm (depending on the monitor used) (Fig. 26.5).
13. Place self-retaining clamp, and using the handle of the scalpel blunt dissect the periosteum (Figs. 26.6 and 26.7)
14. Position hand twist drill perpendicular against the calvarium and begin to drill burr hole:
    (a) Hand twist drill bit for initial five or six turns until drill bit is well seated into outer table (Fig. 26.8).

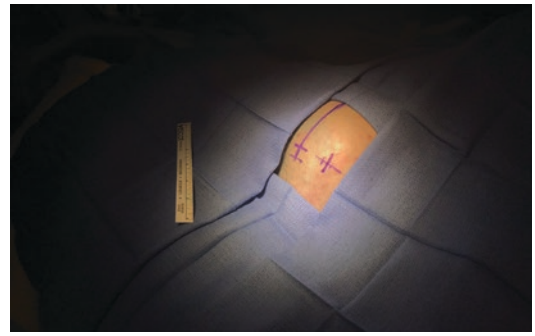

Fig. 26.4 Demonstrates how sterile towels are applied as an additional barrier

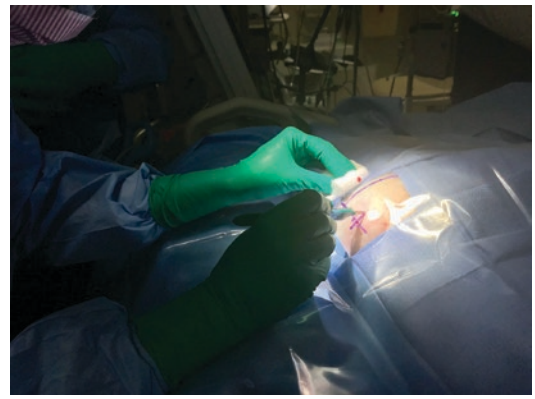

Fig. 26.5 Shows final sterile field and initial incision of scalp

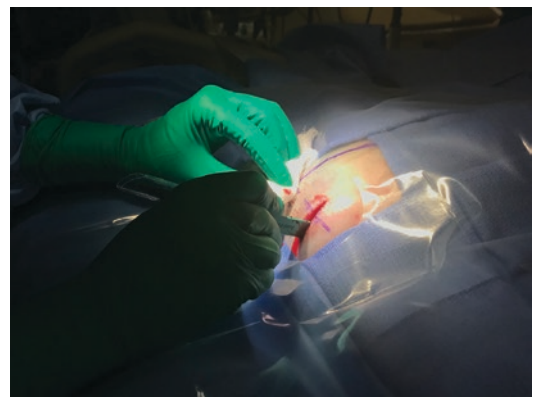

Fig. 26.6 Demonstrates use of blunt end of scalpel to dissect the periosteum away from the skull

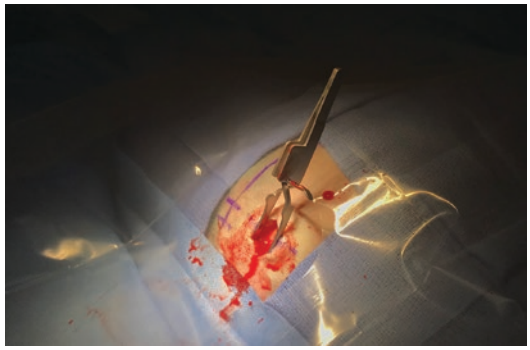

Fig. 26.7 Shows self-retaining clamp in place

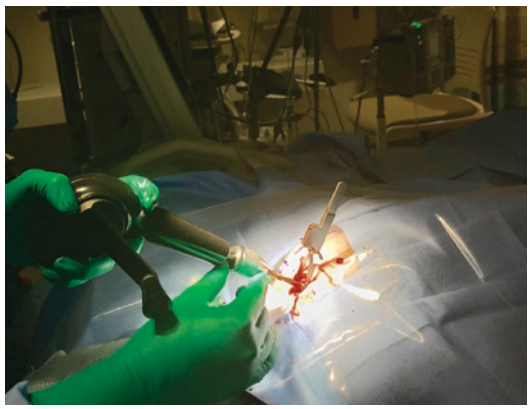

Fig. 26.8 Demonstrates grip of knurled collar for initial turns

(b) Once trajectory is established, continue to drill holding consistent pressure, being careful not to lean into drill with body weight (Fig. 26.9).
(c) Drill through the central medulla until you reach the inner table. You will know when you've reached the inner table when the drill bit "catches."
(d) Hand twist the drill as you pull back slightly to help prevent plunging. Stop when the drill releases freely.

15. Clear any remaining bone fragments from the burr hole site.
16. Using 11 blade, place a cruciate incision in the dura ensuring adequate resection of dura for single or multiple monitor placements (Fig. 26.10).

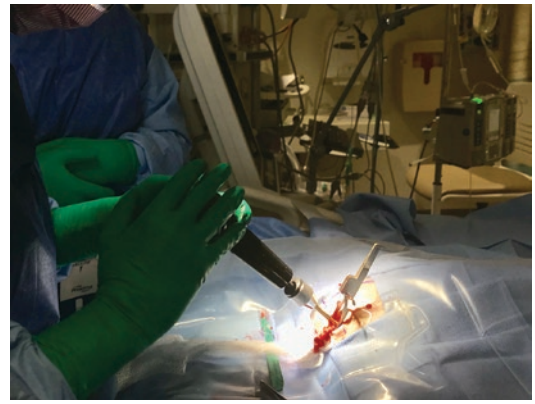

Fig. 26.9 Demonstrates proper body posture and hand placement during drilling, after initial trajectory established

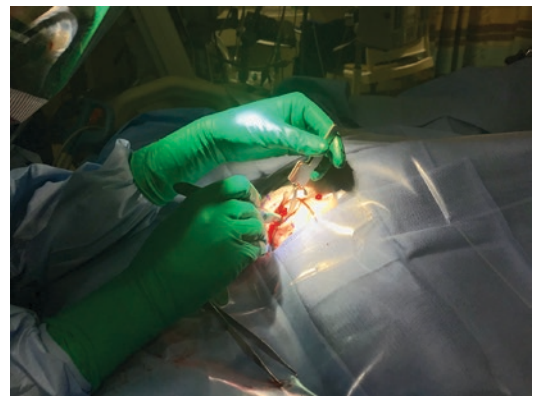

Fig. 26.10 Illustrates incising of dura with 11 blade scalpel

The following steps and supplies will be dependent upon the monitor that your institution uses.

Tunneled IPM (Codman)

1. Gather appropriate monitors, cables, and wires. Have staff begin setting up while patient is being prepped for burr hole placement.
2. Follow above steps for burr hole placement.
3. Using a tunnel device, make a communication from the burr hole to approximately 4–6 cm posterior.

4. Remove trochar from tunnel device and leave sheath in place.
5. Zero monitor
   (a) Submerge the most distal 3 inches of the Codman into sterile normal saline solution and zero the bedside monitor.
6. Pass the distal end of the wire through the tunneling sheath toward the burr hole.
7. Remove tunneling device and insert Codman approximately 2 cm deep into the parenchyma.
8. Ensure that an appropriate waveform and ICP are obtained prior to closing.
9. Suture burr hole site closed with 3–0 monofilament.
10. Place a purse string suture at exit site and wrap excess suture material in overhand fashion proximally along wire (this will secure the wire as well as leave a suture in place to close with upon removal).
11. Dress site with transparent dressing.

Subdural Screw or "Bolt" (Camino)

1. Follow the above steps for burr hole placement.
2. Place the subdural screw perpendicularly into calvarium and hand tighten.
3. Maintaining sterility and with the assistance of nursing, connect Camino wire to monitor.
4. Zero the Camino monitor to atmosphere prior to placement in vivo.
5. Thread IPM monitor through screw and secure.
6. If your facility utilizes multimodality monitoring, place these monitors now
   (a) Hemedex Quad Lumen Bolt placement sequence
      (i) Insert ICP (Camino) wire into the longest port.
      (ii) Once placed, hold white Luer-Lock collar and white static collar most proximal to clear tubing and withdraw until black line is fully exposed. No white should be visible beneath. Secure Luer-Lock (Fig. 26.11).

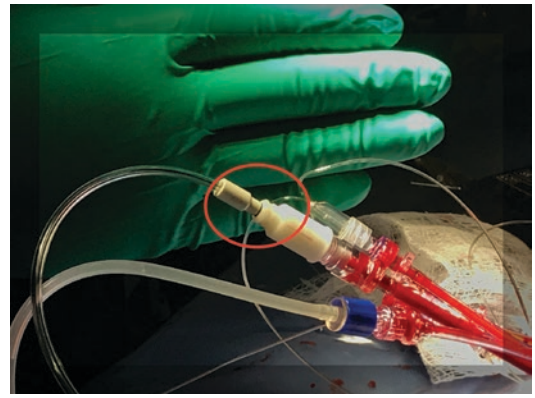

Fig. 26.11 Illustrates black marking that will be visible after Camino monitor inserted into the parenchyma and withdrawn

      (iii) Insert introducer into one of the two medium length ports and remove metal stylet.
      (iv) Insert Licox probe ($PbtO_2$ and brain temperature monitor) into the medium-length port.
      (v) Insert introducer into the second medium-length port and remove metal stylet.
      (vi) Insert microdialysis probe into the final medium-length port and secure.
      (vii) Insert cerebral blood flow (CBF) into the shortest port and position the probe at the 6 cm mark that is visible at the base of the bolt.
         1. This probe is very fragile and easily damaged with frequent manipulation. You may find it more efficient to place this probe first, leaving the more rigid probes for later.
7. Once all monitors are determined to be functioning and ICP waveform is appropriate, suture the burr hole site closed.
8. To dress the bolt, wrap base with gauze and secure with transparent dressings. For multimodality monitoring, it may be helpful to bend an arm board about ¼ of the length down to a 90-degree angle to support wiring (Figs. 26.12 and 26.13).

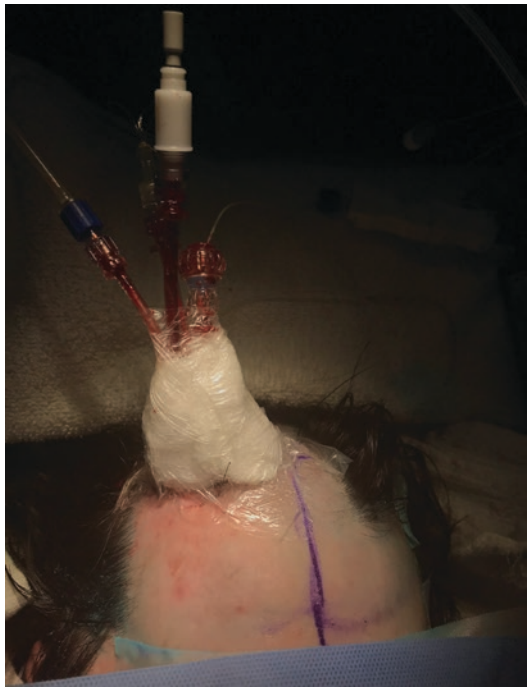

Fig. 26.12 Demonstrates dressing with gauze wrap and transparent dressing

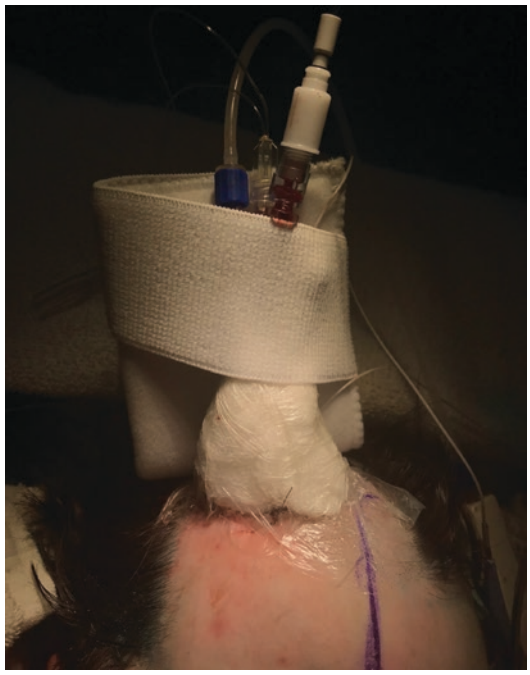

Fig. 26.13 Demonstrates arm board used as support for wires

Complications

Practitioners may encounter technical difficulties with monitors, wiring, and placement. Ensure that all monitors are plugged in and turned on prior to opening sterile packaging. To avoid insertion complications, incise the dura fully. This is especially important when inserting multimodality monitors. Doing so will prevent repeated attempts at insertion of the fragile fiber-optic wires.

Keys to Success, Perils, and Pitfalls

- Avoid areas close to fractures, abscess, hematoma, and pneumocephalus to prevent false readings.
- Always perform imaging after placement to confirm correct positioning.
- Make your incision large enough to fit the retention clamp in easily.
- Bluntly dissecting the periosteum with the back end of the scalpel will give the drill bit better contact with the bone.
- When starting the burr hole, turn the bit by the knurled collar for the first few turns to better control your trajectory.
- Do not press your body weight into the drill.
- Pay attention to the tactile feedback while drilling and you will know which table of bone you are in.
- After passing through the center medulla, you will feel a difference in the drill. At this point, pull back slightly; the drill should not come out easily. You will have just entered the inner table. Continue to twist by the knurled collar of the drill, maintaining slight traction on the drill as you proceed. When you've fully penetrated the inner table, the bit will free itself. Doing this will prevent plunging the bit.
- Ensure that you clear all bone fragments from the burr hole.
- Penetrate the dura completely with an 11 blade, in a cruciate fashion. Doing so will prevent repeated removal and manipulation of the sensitive fiber-optic wires.

Table 26.3 Keys to success

Do's	Don'ts
Completely dissect the periosteum away from calvarium to facilitate drilling	Do not place in area concerning for superficial or intracranial infection
Hand turn the drill by the knurled collar initially for better control	Do not place directly into hematoma, pneumocephalus, or fracture
Note the tactile feedback while drilling	Do not lean body weight into drill
Apply slight traction when passing through the inner table to prevent plunging	Do not remove bolt while wires still in place
Clear all bone fragments from burr hole	
Completely penetrate dura with scalpel or needle punctures	
When having difficulty passing a wire through a bolt, turning the bolt 45° in either direction may facilitate passing	
Pull back on scalp to gain closer proximity to bolt while suturing for better hemostasis	

- When placing multimodality monitors such as a quad lumen, pass the most fragile wire first. This will give it room to find a path past any intact edges of dura that stiffer wires may pass more easily.
- If having trouble passing wires, remove any already in place and turn the bolt 45° in either direction. Attempt the pass again.
- Always confirm waveforms and values prior to suturing, dressing, or breaking sterile.
- When suturing around a bolt, place traction on the scalp to pull the incision anteriorly or posteriorly. This will allow placement of a suture closer to the base of the bolt and create a tighter closure, with less bleeding.
- Never remove a bolt with wires in place (Table 26.3).

CPT Coding

- CPT 61107: Twist drill hole(s) for subdural, intracerebral, or ventricular puncture; for implanting ventricular puncture; and for implanting catheter, pressure recording device, or other intracerebral monitoring devices
- CPT 61210: Burr hole(s), with aspiration of hematoma or cyst, intracerebral for implanting ventricular catheter, reservoir, EEG electrode(s), pressure recording device, or other cerebral monitoring devices (separate procedure)

Summary

Intraparenchymal pressure monitoring is a safe, effective, and fast method for reliable ICP monitoring. It can be used for most patients experiencing or at risk for increased intracranial pressures. Additionally, specific patient populations, such as those with a traumatic brain injury, have improved outcomes with ICP monitoring. Debate remains about the use of ICP or EVDs, but literature continues to support the efficacy of ICP monitors over EVDs. Given the ease of placement and time restraint on neurosurgery faculty, even those institutions with limited resources have the ability to provide this procedure with use of their advance practice providers and non-neurosurgical physicians.

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Lumbar Puncture and Drainage

27

Lorraine Wiercinski and Colleen Christiansen

Introduction

This chapter will give an overview of the practice known as lumbar puncture with or without placement of a lumbar drain for the purpose of cerebrospinal fluid (CSF) diversion. The following will examine the many indications, pitfalls, and common complications associated with this procedure which is typically performed at the bedside. It should be noted that at no time should antibiotics or antiviral medications be withheld in patients where strong suspicion of meningoencephalitis or meningitis is suspected while waiting for CSF to be obtained.

Indications

The primary purpose of lumbar puncture (LP) is for cerebrospinal fluid sampling to aid in the diagnosis of infection, to confirm a suspected diagnosis of subarachnoid hemorrhage, and to sample fluid to aid in the diagnosis of a multitude of primary CNS disease processes including normal pressure hydrocephalus and idiopathic intracranial hypertension, multiple sclerosis, Guillain-Barre, etc. Additionally, LP can be used to administer medications such as anesthesia and antibiotics.

The primary purpose of lumbar drain placement is for cerebrospinal fluid diversion. This diversion is useful during intracranial procedures and to manage postoperative complications where CSF leak is problematic. Lumbar drains are also commonly used during abdominal aortic aneurysm and TEVAR procedures to decrease spinal cord ischemia.

Performed at the bedside using anatomical landmarks, using bedside ultrasonography to assist in landmark identification in the morbidly obese or in the radiology suite where contrast may be administered to aid in diagnosis of certain conditions, lumbar puncture is an essential part of critical care medicine and remains a fundamental skill.

Contraindications

The patient's coagulation profile including platelet count and medical history such as renal failure, cancer, and use of oral anticoagulation are some of the things to consider.

It is imperative to ascertain brain imaging to rule out space-occupying lesions in patients with

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altered mental status. Failure to do so can result in life-threatening herniation and death if lumbar puncture is performed. Patients with space-occupying lesions such as subdural hematoma, epidural hematoma, and tumors as well as those with meningitis often also have concomitant cerebral edema. Herniation is thought to occur secondary to the sudden decrease in pressure surrounding the spinal cord, thus precipitating downward movement of the intracranial contents.

Non-communicating hydrocephalus is also a known contraindication to lumbar puncture.

Ruptured cerebral aneurysm is a relative contraindication, and caution should be exercised so as not to alter the transmural pressure of the aneurysm wall which can precipitate re-rupture.

Chiari malformation is a relative contraindication unless prior surgical correction has taken place.

In general, any patient with elevated PT, PTT, and INR should not undergo lumbar puncture until these values have been normalized. It is accepted practice to perform lumbar puncture in patients taking oral aspirin. Plavix is a relative contraindication, and platelet transfusion should be considered if CSF sampling is critical. In general, a platelet count of 50,000 per cubic millimeter or higher is considered safe.

Any infectious or disease process located over the lumbar area where the lumbar puncture is to be performed is also contraindicated.

Suspected acute spinal column trauma is also a contraindication to performing lumbar puncture.

Anatomical Review

The neuro axis consists of the brain and spinal cord protected by osseous structures. These neural structures are further protected by the ~150 cc of spinal fluid that cushions these structures as well as provides filtration to maintain the perfect homeostatic environment.

Cerebrospinal fluid is clear and colorless and is synthesized via arterial blood and specialized cells located in the ependymal lining of the ventricular system and the choroid plexus. This fluid is continuously made at a rate of approximately 20 cc/h accounting for up to 500 cc/day. The main functions of CSF are to cushion the spine and brain, supply nutrients, and remove products of metabolism. Although the electrolytes, pH, and glucose levels are all similar to plasma, anytime blood is detected within the CSF should prompt a thorough investigation.

The brain and spinal cord are protected by a "PAD," an acronym for the three membranes which line these structures. The pia rests directly next to the brain and spinal cord, the arachnoid space under which the cerebrospinal fluid flows and the thicker, protective dura mater. These membranes terminate in the sacral region where they all fuse and end at a structure known as the filum terminale.

The lumbar spine contains five vertebrae (or six in those who have a lumbarized sacral vertebrae). Lumbar puncture should always take place ideally at the intercristal line which is the line that bisects the spinous processes longitudinally and the iliac crests horizontally. This line roughly corresponds to the L4-L5 level in most cases (Figs. 27.1 and 27.2).

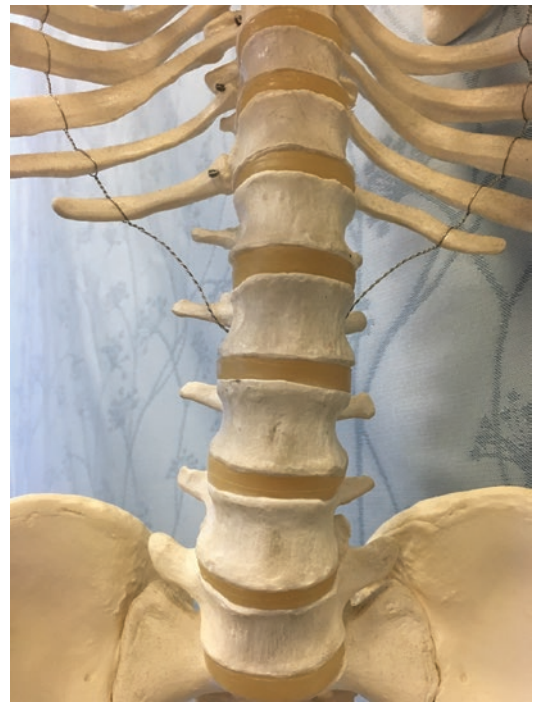

Fig. 27.1 Lumbar spine anterior view

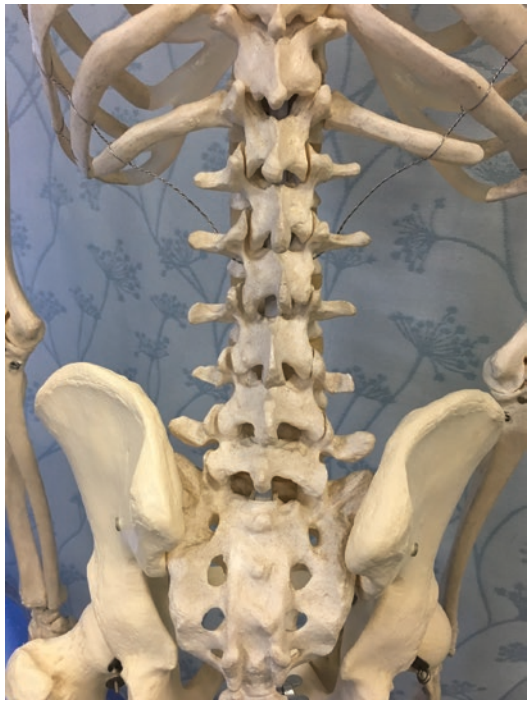

Fig. 27.2 Lumbar spine posterior view

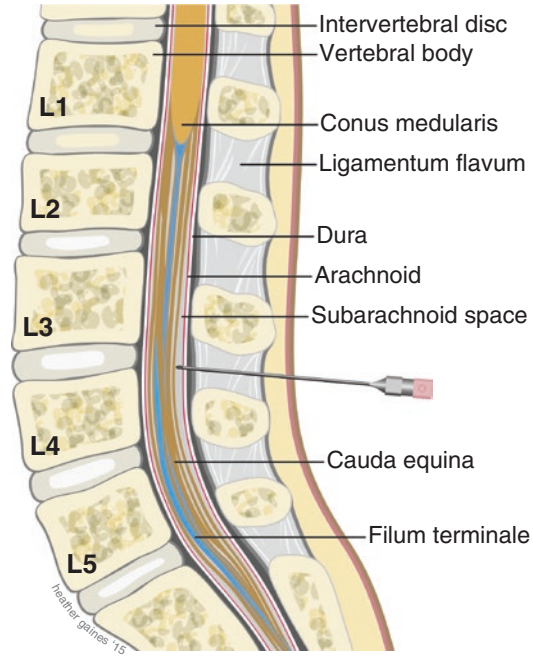

Fig. 27.3 Shows the angle of the needle with stylet entering into the L3-L4 space. Additionally shows the layers of meninges and spinal anatomy including cauda equina and filum terminale

The spinal cord begins in the medulla and terminates at the cauda equina which is at the level of L1 (first lumbar vertebrae). Cauda equina is a bundle of spinal nerves which ends at the level of S2 (second sacral vertebrae) (Fig. 27.3).

Preparation

Prior to performing the LP, review neuro axis imaging, lab values, and medication lists to identify any contraindications. Inspect the skin directly over the lumbar vertebrae to identify potential infection.

As with all invasive procedures, informed consent must be obtained. Informed consent should include all risks and potential harm.

Conscious sedation may be needed for a patient to remain in position for the entirety of the procedure. Additionally, local anesthetic is needed to prevent pain during the procedure. Many LP trays come supplied with lidocaine.

The equipment needed for the procedure includes sterile gloves, surgical cap, surgical mask, lumbar puncture tray, and sedating medications if needed. A lumbar drain kit is needed with lumbar drain bag for drain placement.

Prior to the procedure, positioning needs to be considered. The lateral recumbent position will reflect a true opening pressure which is needed in most disease processes for diagnosis. However, seated position with head down is technically easier but will not provide a reliable opening pressure.

Procedure

Patient should lay in lateral recumbent position with the knees flexed up to chest and the head forward, chin to chest. It is helpful to have an assistant across from you to help the patient achieve this position.

Open the lumbar puncture tray in sterile fashion and don sterile gloves and surgical cap and mask (Fig. 27.4).

Fig. 27.4 Standard lumbar puncture kit

Prepare the area with sterile povidone-iodine solution or chlorhexidine prep in concentric widening circles to ensure a large enough area for draping. This is usually included in the LP kit (Fig. 27.5).

Make sure to mark the area of insertion by creating a mark in the skin where the superior iliac crest lines bisect at the spinous process which is approximately the L4-L5 interspace, also known as the intercristal line or Tuffier's line. Using a skin marker can be helpful. Alternatively, one may press the fingernail to create a dent in the skin as a skin marker may not be included in most traditional LP kits (Fig. 27.6).

Local anesthetic is introduced first as a wheal and then into the deeper tissues. Ensure the bony areas are anesthetized since needle touching the bone can cause the most pain.

Conscious sedation may be used if necessary.

Lay out the CSF collection bottles in the LP tray and assemble the manometer attaching it to the three-way stopcock (Fig. 27.7).

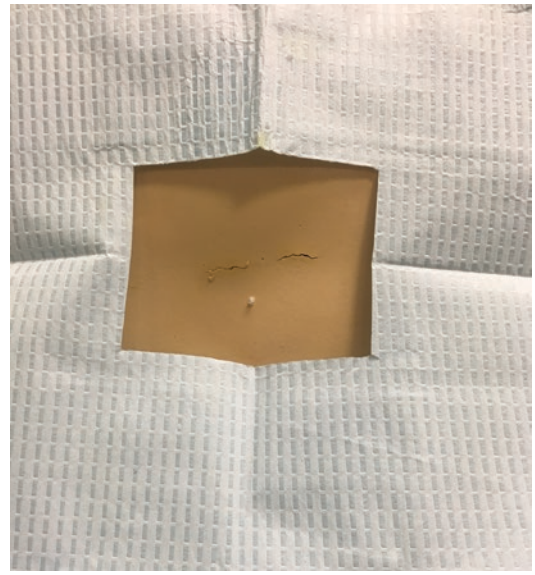

Fig. 27.5 Sterilely draped lumbar spine

Fig. 27.6 Illustrates the lumbar puncture kit set up for the procedure

Entry Point

> In an adult use the L4-L5 interspace and L3-L4 interspace as an alternative. In pediatrics L4-L5 is preferred over L3-L4 [1].

It is often crucial to understand and visualize the anatomy to ensure proper technique.

The needle passes through the following in sequential order: "skin, subcutaneous tissue, supraspinous ligament, interspinous ligament,

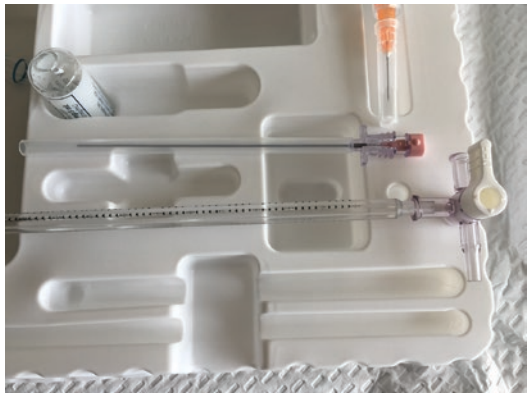

Fig. 27.7 Illustrates the monometer with three-way stopcock connected and the needle with stylet intact

ligamentum flavum, epidural space containing the internal vertebral venous plexus, dura, arachnoid, and finally the subarachnoid space" [2].

Needle Insertion

Using an atraumatic needle such as Quincke, be sure the bevel is upright or sagittal plane to separate rather than cut the fibers of the thecal sac (toward the side of the patient that is facing upright) in the midline with a slight 10°–15° angle cephalad and aims toward the umbilicus via an imaginary line. This technique should decrease post-procedure leakage of spinal fluid and post-procedure headache (Fig. 27.8).

The needle is steadied close to the skin by the non-dominant hand, while firm steady pressure is applied using the dominant thumb and forefinger advancing slowly until a slight pop is felt – approximately 1–1.5 inches. For children, shorter needles are used. For infants, use 1.5 inch needle. For children 2 years to 8 years, use 2.5 inches, and for older than 8 years, use 3.5 inches. A longer 8″ needle may be required for obese patients, and the use of ultrasound may be helpful in mapping out the bony landmarks just prior to needle entry.

The pop often described is the dura, and it is at this point where the stylet is removed and the needle is observed for the return of CSF. If no CSF is encountered, the stylet is replaced and the needle may be advanced in 2 mm increments, remove the stylet, and again observe for CSF return. If CSF fails to flow, you may need to bring the needle and stylet back out to just below the skin to redirect. If a bone is encountered, this usually means that the needle is off to the lateral of the midline entry. Simply redirect the needle toward the midline (Figs. 27.9 and 27.10).

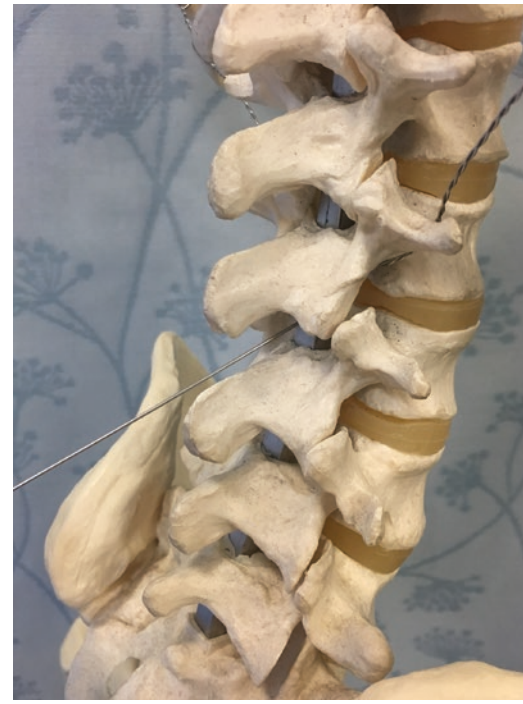

Fig. 27.8 Lateral view of the lumbar spine showing the spinal needle at the proper angle to access the subarachnoid space

If the patient notes pain down one leg, pull the needle back and change the angle slightly opposite the affected leg. If the lumbar puncture is traumatic, some blood tinge will be noted in the cerebrospinal fluid but should clear by the end of the CSF collection. If the flow is poor, you may rotate the needle 90° so as to move the opening away from a nerve. If the needle is clogged with blood, you should obtain a new needle and repeat the procedure.

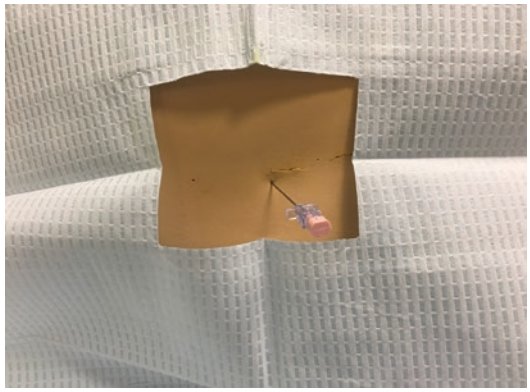

Fig. 27.9 This is the lumbar spine with needle and stylet entering the L3-L4 space

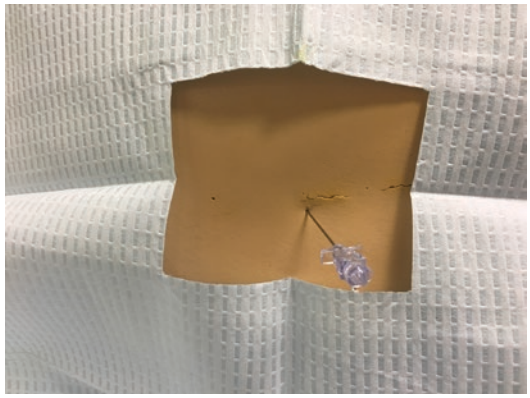

Fig. 27.10 The stylet is removed and CSF is flowing from the needle

CSF Manometry

The patient must be in the lateral decubitus position. Opening pressure should be obtained immediately following access of cerebrospinal fluid. Once CSF flow is encountered, the three-way stopcock and manometer assembly can be attached to the needle after the stylet is removed (Fig. 27.11).

The cerebrospinal fluid will flow up the manometer, and once the pulsation of the meniscal line stabilizes, the pressure can be recorded. If the pressure exceeds 25 mmHg in the manometer, the patient should be observed for deterioration in neurological status (herniation syndrome) (Fig. 27.12).

Fill tubes in sequence from 1 to 4 with 2–3 cc of CSF in each tube. (See below for CSF tube

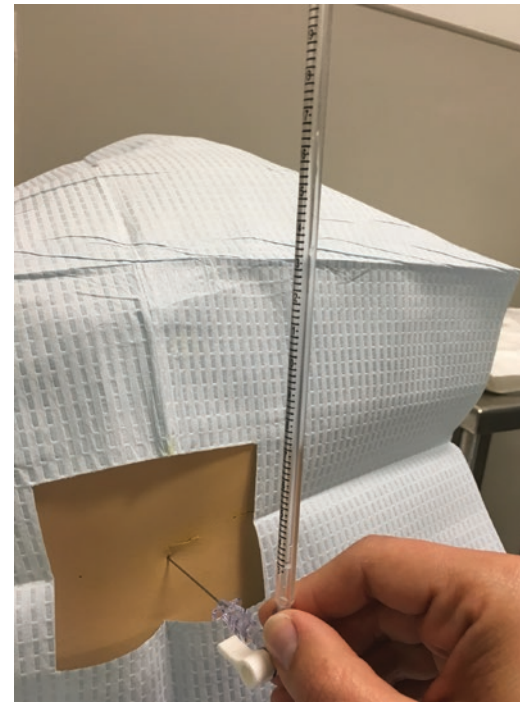

Fig. 27.11 Showing the monometer attached to the needle and CSF flowing up the cylinder

Fig. 27.12 Sterilely draped patient with monometer measuring ICP. Note the patient is in the lateral recumbent position

collection designations.) After adequate CSF sampling has been obtained, the stylet is placed back in the needle prior to removing the needle, and a dry sterile dressing is placed (Figs. 27.13 and 27.14).

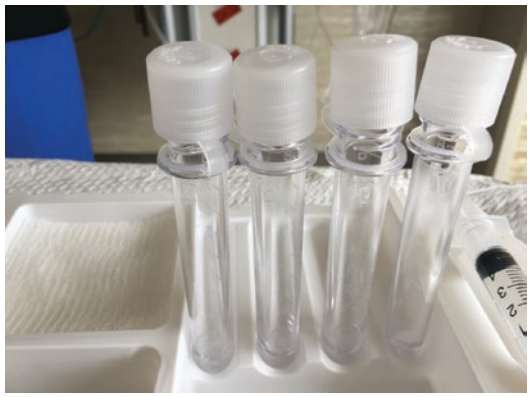

Fig. 27.13 CSF collection tubes set up in sequence 1–4

Fig. 27.14 CSF being collected sterilely

Lumbar Drain Placement

Drain preparation is similar to LP preparation. The patient must be in the lateral recumbent position.

Open and set up lumbar drainage kit; note that a 14–16 gauge Tuohy needle replaces the Quincke style needle and this will allow for safe passage of the catheter into the intrathecal space. Note the markings on the side of the needle which are 1 cm spaced apart.

Note the end of the catheter with the fenestrations; this is the end that is advanced inside the patient.

Flush the tubing with sterile saline prior to start of procedure.

Guide wire is inserted into the lumbar catheter.

Spinal access is as described above at the L4-L5 interspace.

Once you are in the thecal sac and CSF flow is returned, the bevel is turned up toward the head and the stylet is removed.

The tubing is then inserted through the needle into the thecal sac.

Do not pull the tubing back once insertion has begun because the needle can shear the tubing causing breakage.

Once the catheter is in the correct position, approximately three levels above the insertion site, the needle is gently pulled back over the catheter.

The guide wire can now safely be removed while the catheter is stabilized and secured next to the skin with a suture.

The lumbar drain cap is secured to the end of the tubing, and a small free tie can secure the catheter to the cap.

The lumbar drain can now be secured with sutures to the back and a dry sterile dressing is placed on top.

The catheter can now be connected to the lumbar drain system after it has been primed with sterile normal saline solution.

If difficulty is encountered, the entire needle and tubing are removed, and the procedure is started over.

The drain system can be transduced to obtain pressures when the patient is flat.

Post Procedure

Patients can lay flat for approximately 1 hour following the procedure although no studies have confirmed that this helps reduce post-procedure headaches.

CSF Interpretation

Although specific neurological disease work-up may be requested and managed by other services, it is helpful to understand what specific spinal fluid testing is required so that appropriate amounts of fluid may be collected.

CSF vials are filled in a specific sequence and labeled in the same sequence to compare cell counts of the first vial to the fourth vial. Therefore, tubes #1 and #4 are cell count. Tube #2 is protein and glucose. Tube #3 is gram stain, culture, and cytology. Additional tests can be run off the fourth vial, but if a significant number of tests are needed a fifth vial can be sent.

Note the color of the CSF vials. Yellow or xanthochromia indicates old blood or high protein levels, increased bilirubin, presence of carotene, and melanoma. High protein is seen in meningitis, whereas xanthochromia is typically seen in subarachnoid hemorrhage (SAH). Pink tinged indicates blood. If the blood clears by vial 4, the blood is associated with a traumatic tap. In the case of a traumatic tap, correction of red blood cells (RBC) is needed to identify the true value of white blood cells (WBC) in order to identify infection. To calculate pleocytosis (WBC count), use the following formula:

$$\frac{\left(\text{CSF RBC} \times \text{Blood WBC}\right)}{\text{Blood RBC}} \times \text{CSF WBC} = \text{True WBC CSF count}$$

RBC greater than 10,000 indicates SAH. If SAH is suspected and not shown on noncontrast head CT scan, either a CT angiogram or a formal angiography of the head and neck should be obtained.

Other common testing depends on the patient's medical history, age, presentation, and comorbidities: herpes simplex virus (HSV), venereal disease research laboratory (VDRL), and cryptococcus.

For ruling out malignancies, CSF for cytology and flow cytometry (fresh sample hand delivered to flow cytometry area) are often required. Please check your hospital policy regarding collection and handling of such specimens.

In acute myelitis the following should be considered: HSV types 1 and 2 (PCR), VZV (PCR), enteroviruses (PCR), *Borrelia burgdorferi* sensu latu (serology AI), HIV (serology), and tick borne encephalitis virus (only in endemic areas).

Additional CSF can be collected to rule out autoimmune processes as well as rare conditions. However, a thorough medical, social, and family history needs to be obtained to effectively determine the pertinent testing.

Complications

LP is generally a safe procedure with largely benign complications, though risks are still associated with the procedure. Using an atraumatic needle such as a Quincke can aid in preventing most complications. Headaches are the most prevalent complaint reported in up to nearly one third of all patients and are most likely due to intracranial hypotension from decreased CSF. CSF is continually produced which should limit the headache. However, lying flat for an hour, administration of analgesics, and caffeine can help relieve the headache temporarily. If the headache persists, a blood patch may be needed.

Nerve root irritation can occur during the procedure. This is when the needle is pressing directly on a nerve. The patient may experience pain shooting down one leg or in their groin. If this occurs, replace the stylet and remove the needle slowly until the pain has subsided. Check to see if CSF continues to flow from the needle. If there is no CSF return, the needle may need to be redirected slightly and advanced.

Infection or meningitis can occur but it is rare. Broad spectrum antibiotics are used until further CSF sampling can identify a specific culture.

Cerebral herniation is the most serious but also extremely rare. Herniation is thought to be caused by a sudden drop in intracranial pressure (ICP) which causes the brain to herniate through the foramen magnum. Only is this a risk if the patient has elevated ICP to begin with as in intracranial masses or bleeding. Therefore, CT scan is crucial prior to LP to identify any masses or bleeding.

Keys to Success

Positioning is key to any procedure. If the patient is in the lateral recumbent position, make sure the shoulders and hips are both perpendicular to the bed. The patient cannot be rotated as this will alter the entry point and make obtaining CSF difficult.

In adults while lying in the lateral recumbent position, the L3-L4 space is the easiest to access. Conversely, L3-L4 may be problematic in children. In obese adults, the easiest access is sitting with chin tuck; however, the opening pressure will not reflect intracranial pressure.

Never pull CSF with a syringe. The application of this negative pressure force can precipitate bleeding.

CPT Codes

- 62270: lumbar puncture, diagnostic
- 62272: lumbar puncture, therapeutic (needle or drain)
- 62273: lumbar puncture with injection (anesthesia, medication, blood patch)
- 77003: add-on code for fluoroscopy

Summary

In conclusion, LP is an essential skill as an advanced provider. The procedure is relatively safe and can guide management of numerous neurological, infectious, or oncologic diseases. Reviewing neuroimaging can help to greatly reduce the most severe complications. However, obstacles may prevent the provider from successfully completing the procedure. Proper positioning for body habitus can aid in obtaining CSF. Practicing with ultrasound or using fluoroscopy can assist in identifying the best angle and placement of the needle. Finally, never wait for an LP or CSF culture to start antibiotics or antivirals. Broad spectrum meningitic coverage with antibiotics and antivirals should be started immediately.

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Additional Resources

The New England Journal of Medicine video of lumbar puncture is a great resource on this topic. www.nejm.org/doi/full/10.1056/NEJMvcm054952.

Ultrasound Guidance in LP. www.youtube.com/watch?v=QZVjQ2Fwj4Q.

Part VI

Abdominal Procedures

Enteral Access

28

David Shane Harper

Introduction

Critically ill patients routinely require therapies such as pharmacologic sedation, mechanical ventilation and prolonged immobilization. In scenarios such as these, oral intake and an ability to convey nausea or impending vomitus can be hindered. Enteral access is thus achieved as a means to provide nutrition, administer medications and decompress gastric/enteric secretions. To utilize an enteric tube a provider may choose to utilize either a gastric or postpyloric placement, via either a nasal or oral route, depending on the needs of the patient and a multitude of clinical considerations.

Indications

1. Need for short term enteral access for the administration of medications
2. To initiate enteral nutrition within the first 24–48 hours in patients who cannot consume adequate nutrients to meet their caloric need
3. Decompression of upper gastrointestinal tract secretions/fluids
4. Removal of ingested toxins

Contraindications

- Relative: Known esophageal varices, recent banding of esophageal varices, alkaline ingestion
- Absolute: Cranial/maxillofacial trauma, coagulopathy

Risks/Benefits

As with all procedures, the risks and benefits of each procedure must be weighed and honestly conveyed to the patient. When discussing benefits and risks with patients and/or families, include:

- Benefits of enteral access includes:
  1. Allows for early implementation of nutrition, administration of medications and immediate decompression of the stomach.
  2. Nasogastric (and nasojejunal) tube placement is a very common procedure within the critical care unit and most bedside staff is very familiar with various enteral tube use and function.
  3. Although uncomfortable at placement, once in place the tube is more of an annoyance than painful.
  4. Placement and removal can be performed at bedside in a timely manner.

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- Risks of enteral tube placement includes:
  1. Malposition of the tube with possible injury to the airway, lung parenchyma and or pleural space
  2. Injury to the nasal cavity, posterior pharynx, esophagus, stomach or duodenum.
  3. Risk of bleeding
  4. Risk of infection with prolonged use. Specifically (but not limited to) sinusitis on the side the tube is located.

Preparation

Successful placement of any enteric tube begins with an appropriate patient evaluation and preparation. Once it is determined that a patient will benefit from the placement of an enteric tube, the clinician must determine the: goals to be accomplished with enteric tube placement, enteric tube selection, enteric tube route and probable duration of need for enteric tube.

Tube Selection

Nasogastric and orogastric tubes are considered large bore tubes with sizes usually greater than 14 French (14–24 French in adults) [1]. These tubes are usually made of polyvinyl material that allows for greater strength and durability. Given their size and stiffness, these tubes allow for higher negative pressures to be applied to them without tube deformation or flattening. This allows for the efficient decompression of liquids which may be of varying densities. Given their size, these tubes also allow for the administration of medications with less likelihood of becoming clogged.

Nasoduodenal or nasojejunal tubes which are ideally placed postpylorically and intended for enteric nutrition. These tubes are smaller (8–12 French) and less rigid due to their construction of polyurethane, silicone or a mixture of the two. They are usually better tolerated than larger gastric tubes. Due to their composition and structural characteristics these tubes tend to not be amendable to any form of negative pressure. Liquid medications may be administered but crushed tablets or opened capsules are infamous for clogging these tubes. If a nasoduodenal or nasojejunal tube is chosen to be placed, premedicating the patient with a gastric promotility agent may add in placement.

Route

Once a tube has been chosen, the choice of nasal route versus oral route should be made. This is usually a very obvious answer as ideally an orogastric tube would be placed only in an intubated and sedated patient. Awake and nonventilated patients do not tolerate the presence of just an orogastric tube. One can utilize a nasogastric tube in an intubated patient though, especially if one expects the patient to be extubated before the gastrointestinal tract can be used. In this scenario, placing a nasogastric tube at the time of intubation versus orogastric tube will save your patient future discomfort after extubation.

Equipment (Fig. 28.1)

1. Chosen enteric tube
2. Water based lubricating jelly or 2% viscous lidocaine
3. A 60 cc piston syringe (also known as a Toomey syringe)
4. Glass of water with straw
5. Emesis basin

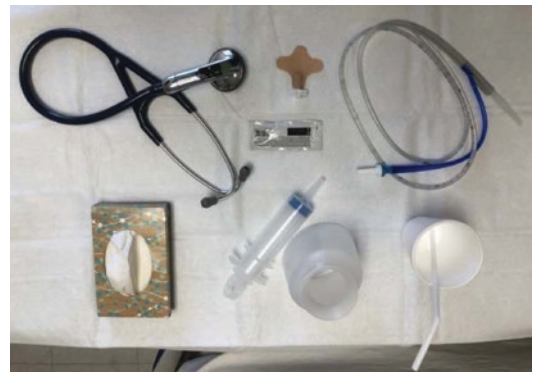

Fig. 28.1 Equipment for procedure

6. Suction tubing and container
7. Tape or securement device
8. Box of tissues (nasogastric tube placement causes many patients to tear up and tissues are useful to remove excess lubricating jelly)
9. Access to suction (ideally wall suction that is able to be set variable negative pressures and time intervals)
10. Personal protection equipment (gloves and eye protection)
11. Stethoscope (for gastric tube placement)

Personnel

A provider or nurse competent in the placement of enteric tubes along with a bedside nurse or nurse's aid are all the personnel needed.

Positioning the Patient

Awake and conscious patients will need to be positioned in a sitting position. If a patient cannot assume the sitting position, the patient should be placed in the most upright position tolerated. Intubated and ventilated patients should be placed in the semi Fowler position if able. It is possible to place an enteric tube when a patient must remain supine, but it does add difficulty. Once the patient has assumed the sitting position, allow the patient to hold the cup of water with a straw if able. Once all equipment has been gathered, assembled and initiation of the procedure is imminent, have the patient slightly flex their neck. Once the tube has been placed and secured, the patient may resume their position of comfort mindful of the enteric tube and suction tubing's position.

Procedure

Gastric Tube Placement

1. Once all supplies and personnel have been gathered and consent has been obtained, one will need to position the patient. If the patient is awake and alert, a more upright position can be helpful. Ideally the patient will be no lower than the semi-Fowler position.
2. Premedicating the patient with a spray nasal decongestant or 2% viscous lidocaine at this point allows for desired results to be achieved during the time you are gathering and assembling your equipment.
3. With the chosen gastric tube, one measures the distal tip of the tube from the gastric region along the anterior chest wall, up the neck to the pinna of the ear and then to the lips will provide an adequate depth to achieve gastric placement (Fig. 28.2). Nasoduodenal and nasojejunal tubes are usually placed almost in their entirety and do not require measurement.
4. Lubricating the distal end of the enteric tube with water based lubricating jelly (or viscous lidocaine) to aid in placement should be performed.
5. Gently place the distal end of the tube into the predetermined nare with advancement in a posterior direction along the nasal floor

Fig. 28.2 Measuring the nasogastric tube

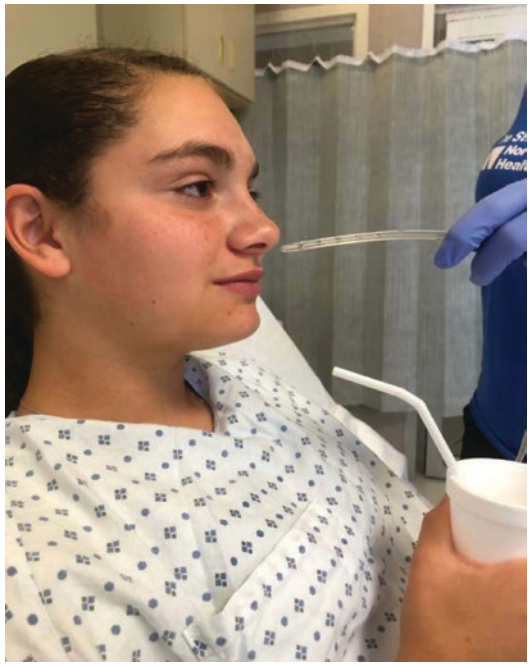

Fig. 28.3 Correct trajectory of nasogastric tube along the nasal floor

Fig. 28.4 Incorrect Trajectory of nasogastric tube. Note cephalad direction

(Fig. 28.3) and not cephalad (Fig. 28.4) with advancement intervals of 2–3 cm at a time.

6. The tube may then be felt in the back of the throat by the patient at the 10–15 cm mark and or the clinician may be able to appreciate a change of direction of the tube. At this time instruct the patient to begin sipping and drinking through the straw of the provided cup of water
7. Advancement of the tube may then continue with larger intervals of roughly 5–8 cm in length as the patient continually swallows the water.
8. Ideally the enteric tube will pass with little resistance and without difficulty to the predetermined depth.
9. Once the tube has been placed to predetermined depth, securing the tube with tape (small strips of tape wrapped around tube and connected atop the patient's nose) or commercially available securement device should be performed.
10. Bedside placement confirmation can be performed with either auscultation over the left upper quadrant of the abdomen as a small air bolus is injected through the gastric tube or appreciating the presence of gastric contents once the tube is connected to suctioning.
11. If neither of these maneuvers provide the expected results and the patient is not in distress, the tube may remain in place until an abdominal radiograph is obtained to radiologically evaluate the tube's position.
12. If at any time during the procedure: the patient becomes short of breath, loses the ability to speak or significant epistaxis is noted, immediately remove the tube and reevaluate the patient.
13. After tube placement has been confirmed, it may be utilized for nutritional/medication administration or decompression.

Nasoduodenal Tube Placement

1. Once all supplies and personnel have been gathered and consent has been obtained, one will need to position the patient. If the patient

is awake and alert, a more upright position can be helpful. Ideally the patient will be no lower than the semi-Fowler position.
2. Premedicating the patient with a spray nasal decongestant or 2% viscous lidocaine at this point allows for desired results to be achieved during the time you are gathering and assembling your equipment.
3. Nasoduodenal tubes being of smaller size and less rigid, are prepackaged with metal stylets inserted in them to aid in placement (Fig. 28.5). This stylet will need to initially remain in place after placement to aid in visualization of the tube on radiograph. After the radiograph is obtained the stylet may be removed. To aid in eventual removal of the stylet after placement is confirmed, one will need to inject a small amount (5–10 ml) of water or saline through the side port of the nasoduodenal tube prior to placing the tube.
4. Lubricating the distal end of the nasoduodenal tube with water based lubricating jelly (or viscous lidocaine) to aid in placement should be performed.
5. Gently place the distal end of the tube into the predetermined nare with advancement in a posterior direction along the nasal floor (not cephalad) with advancement intervals of 2–3 cm at a time.
6. The tube may then be felt in the back of the throat by the patient at the 10–15 cm mark and or the clinician may be able to appreciate a change of direction of the tube. At this time instruct the patient to begin sipping and drinking through the straw of the provided cup of water
7. Advancement of the tube may then continue with larger intervals of roughly 5–8 cm in length as the patient continually swallows the water.
8. Ideally the nasoduodenal tube will pass with little resistance and without difficulty to the 50 cm mark.
9. Once the tube has been advanced to the 50 cm mark, inject 60 ml of air while auscultating over the left upper quadrant. If a gurgle is present, the nasoduodenal tube is likely in the stomach. Injecting another 500 ml of air at this point may help stimulate peristalsis.
10. Slow begin advancing the tube while twisting it in a clockwise rotation. This maneuver aids in preventing coiling of the tube within the stomach. The patient may also be placed in the right lateral decubitus position to allow gravity to aid in passing through the pylorus.
11. If resistance is encountered at this point, slowly inject 10 ml of air and keep advancing.
12. Advance the tube till only 5 cm remains outside the nare.
13. Order an abdominal radiograph.
14. While awaiting for the radiograph to be obtained, one may begin to secure the nasoduodenal tube with tape or with a commercial bridling system (Fig. 28.6).
15. Once the radiograph is obtained and placement can be verified, the metal stylet may be removed slowly from the nasoduodenal tube.
16. At this point the tube may be utilized for nutritional/liquid medication administration.

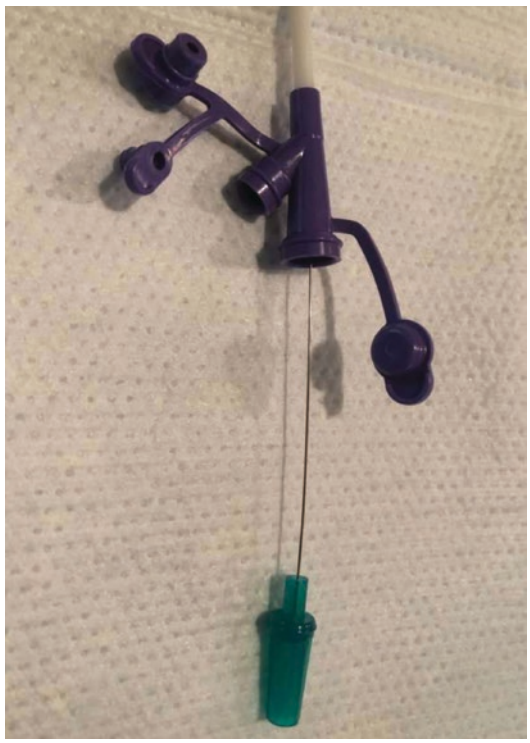

Fig. 28.5 Small bore feeding tube with metal stylet shown

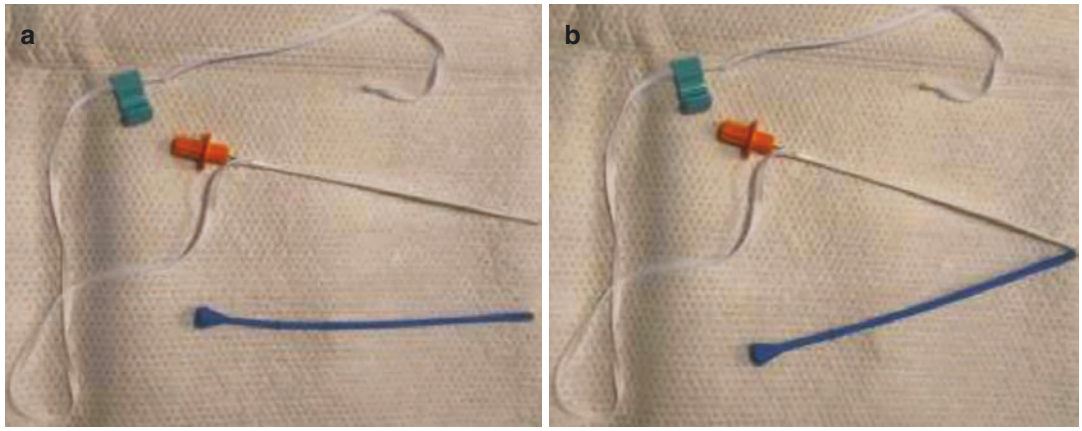

Fig. 28.6 (**a**) Nasal Tube bridal kit; (**b**) Nasal bridal kit with magnets engaged

Complications

As it is with performing a procedure repeatedly, inevitably you'll encounter complications. As the old adage goes "if you've never had a complication, you probably haven't done enough of them". Common complications encountered with enteric tube placement usually involve either malposition of the tube or malfunction of the tube.

Malposition of a 'placed' enteric tube usually entails tracheal placement or failure to reach the gastric body. Determining correct placement is vital before utilizing the enteric tube for nutrition or medications administration. Before initiation of the procedure, a clinician can estimate the depth for a nasogastric or orogastric tube to reach the gastric body. Traditionally, the nose to ear to xiphisternum (NEX) measurement is utilized to estimate depth. The NEX measurement is calculated by laying the tube itself on the patient essentially over the path the tube will traverse from the mouth/nose to the stomach. Starting with the distal tip of the tube at the nose, one measures to the ear and then down the neck and anterior chest wall to the xiphisternum. At this point, the clinician notes the centimeter mark of the tube at the patient's xiphisternum (Fig. 28.2). Unfortunately, research has shown that this method can inadequately determine the correct depth in 17–23% of nasogastric tube placements [2]. Conversely further research has found that measuring in the opposite direction, xiphisternum to ear to nose (XEN) and adding 10 cm allows for the tube to reach the gastric body in most patients [3].

Once a nasogastric or orogastric tube is assumed to be successfully placed several methods may be utilized to help determine correct placement. Insufflation with an air bolus via a 60-milliliter syringe while simultaneously auscultating with a stethoscope over the left upper quadrant of the abdomen may allow for appreciation of a gastric 'gurgle' but this method can be false with some tracheal or parenchymal placement. Immediate return of gastric contents when the tube is connected to suctioning is a reassuring bedside finding but also is not completely conclusive. To obtain objective evidence of correct placement, a chest of upper abdominal radiograph will need to be performed prior to administration of any substance through the orogastric or nasogastric tube.

Nasoduodenal tube placement ideally transverses the gastric body, through the pylorus and enters the duodenum. Unfortunately, radiologically unaided bedside placement of nasoduodenal tubes is often found to unsuccessfully pass postpylorically. To aid in placing the nasoduodenal tube postpylorically, a clinician can: position the patient in the right lateral decubitus position if the tube is found to be in the gastric body allowing gravity to help propagate the tube postpylorically, administer several boluses of air into the gastric body promoting gastric motility and

peristalsis, administer a prokinetic agent before the procedure begins and twist the tube in a clockwise direction to aid in inhibiting coiling of the tube within the gastric body.

Keys to Success, Perils and Pitfalls

Enteric tube placement is a common procedure within the critical care unit and has been for many decades. Since its inception, clinicians have discovered several 'tricks of the trade' to aid in successful bedside placement. Below several scenarios are presented with an accompanying clinical pearl to help aid in determining tube placement.

> The tube is coiling in the back of the patient's mouth.

Coiling in the back of the oropharynx can be caused by several things. First, the tube may be too flexible and upon encountering any resistance will bend. Placing a polyvinyl enteric tube in a cup of ice-cold water for several minutes allows for the end of the tube to become stiffened and thus lessen the tendency for the end of the tube to coil. The enteric tube will acquire a slight curve to the distal end due to sitting in the cup. This curve of the tube is expected and desired. After several minutes you may check the tube and begin once the desired stiffness is achieved. With the curve pointing inferiorly, advance the tube through the nasal passage to the oropharynx. Once the tube has entered the oropharynx, rotate the tube 180° and allowing for the tube to now point posteriorly and thus toward the esophagus during advancement. Secondly, asking the patient (or having an assistant) flex their neck, essentially placing their chin to their chest. Performing this maneuver while advancing the tube allows for the tube to 'follow' the posterior wall of the pharynx and increasing the likelihood of entering the esophagus.

In an intubated patient, ideally the gastric tube will be concurrently placed at the time of intubation. Remembering to place the gastric tube at time of intubation allows for the use of a traditional or video laryngoscope to visually aid in the placement. If conventional methods do not allow for passage of the tube into the esophagus and the patient remains under the pharmacologic effects of intubation, a clinician may place two fingers of one gloved hand into the posterior oropharynx and guide the gastric tube into the esophagus so placement can be achieved.

> How can I tell if I have accidently entered into the trachea in a patient?

Malpositioning of an enteric tube within the trachea can be difficult to determine at bedside in a ventilated and sedated patient. There are several small observations which may help you determine if the tube is within the trachea. First, try to observe for condensation within the enteric tube on the expiratory phase of ventilation. Next, if the enteric tube has been connected to suction, observe to see if the expiratory volumes being returned to the ventilator are reduced. Alternatively, one can "listen" to the end of the enteric tube to try and appreciate air softly blowing through the tube with the ventilation cycle. Lastly, if a tube has been placed within the pulmonary system of a ventilated patient, the patient may have clinical signs of an endotracheal tube cuff leak (or rupture). This occurs when the enteric tube has passed along the side of the endotracheal tube cuff. If this is the case, an audible cuff leak may be appreciated on the expiratory phase of ventilation. If available, colorimetric capnography may also be used to verify gastric tube placement [4].

Fan et al. found that having a patient hold their breath during placement essentially 'blocked' an enteric tube from entering the trachea [5]. This 'no swallow technique' had patients hold their breath once the tube was advanced to the posterior oropharynx versus the conventional method of having patients swallow small sips of water through a straw. While holding one's breath, the epiglottis maneuvers to cover the trachea and the glottis closes. These natural physiologic occurrences thus block the enteric tube from entering the trachea. This technique increased the success of gastric placement while decreasing the likelihood of adverse effects versus the control group who were subjected to a conventional technique.

Malposition of the tube in a conscious patient is suspected if the patient should begin to cough, become short of breath or loses the ability to speak. If the patient at any time during placement loses the ability to speak, one must suspect that the enteric tube has crossed the level of the vocal cords and is impeding their function. Conversely, if the patient can speak normally to you, the likelihood of the tube being within the trachea is very low.

> The patient cannot tolerate enteric tube placement due to gagging.

A sensitive gag reflex can make enteric tube placement difficult. Having a patient pant through their mouth while the enteric tube is being placed can help offset a sensitive gag reflex. If further measures as needed, pharmacologic intervention in the form of topical anesthetics may also be useful.

> The patient says every time they have had a nasogastric tube they have had a nose bleed.

For persons who are prone to epistaxis, premedicating with several sprays of a nasal decongestant, liberal use of lubricating jelly and slow, careful initial placement of the nasogastric tube usually affords a blood free procedure.

> I can never get a nasal bridle to work properly when I place a nasoduodenal tube.

Commercially available nasal bridles are available for securement of some enteric tubes. Nasal bridles are a form of securement that places a loop of material through one nare, behind the septum and back out the other nare. The two ends are then secured once connected to the enteric tube. One of the most common nasal bridle utilizes two positioning probes which each have a magnet on the end of them (Fig. 28.6). One probe is placed in one nare, the other probe in the other nare. They are both advanced simultaneously and once beyond the septum the two magnets connect completing the 'loop'. One of the probes is actually a catheter connected to a length of material and is pulled behind the septum and out the other nare. Most small bore nasoduodenal tube are quite soft and necessitate placement with a prepackaged metal stylet present (Fig. 28.5). This metal stylet is eventually removed after placement but should not be removed until after the abdominal radiograph has been obtained. The metal stylet's presence aids in appreciating its position on the radiograph greatly. Thus, trying to place a nasal bridle with the metal stylet remaining in the tube can be challenging if not impossible as the magnets are attracted to the stylet within the tube. Once the radiograph is obtained and placement confirmed, then the stylet may be removed and nasal bridling attempted.

CPT Coding

43752 - Naso- or oro-gastric tube placement, requiring physician's skill and fluoroscopic guidance (includes fluoroscopy, image documentation and report).

Summary

Obtaining enteric access via enteric tube placement is one of the most common procedures performed within any critical care unit. Critically ill patients are routinely in states of therapy that do not allow for normal oral intake. Placement of a gastric or postpyloric tube allows for the administration of medication, deliverance of nutrition and decompression of gastric/enteric fluids. Gastric tube placement allows for both the administration of substances along with the decompression of gastric fluids. Postpyloric tubes are smaller and less rigid allowing only for the administration of medications and nutrition. Complications can be encountered but are usually easily remedied with simple alterations in technique or with patient aids.

With recommendations such as those of the Society of Critical Care Medicine (SCCM) and American Society for Parenteral and Enteral Nutrition (A.S.P.E.N.) advising enteral nutrition to be initiated within 24–48 hours of following the onset of critical illness, enteric tube placement will continue to be a common procedure that all critical care providers will need to master [6].

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Additional Resources

Nasogastric Tube Insertion- OSCE Guide; https://www.youtube.com/watch?v=WZvIw0SnYrE. 2 May 2015 - Uploaded by Geeky Medics.

29 Percutaneous Endoscopic Gastrostomy Tube Placement

Gena Brawley and Gaurav Sachdev

Introduction

For critically ill patients in the acute setting, optimized nutritional support is key for healing and recovery. Many patients will suffer from dysphagia necessitating both temporary feeding access and longer-term, more established access for feeding. For these patients, a percutaneous endoscopic gastrostomy tube (PEG tube) is often considered for established feeding access. A PEG tube is a long-term feeding access tube placed endoscopically for patient with significant dysphagia.

The PEG tube was initially performed in 1980 as an opportunity to establish long-term enteral feeding access without the need to undergo open or laparoscopic feeding tube placement. PEG tubes are considered safe for placement and long-term use and have quickly become one of the most common endoscopic procedures. The procedure can be performed at the bedside, in the endoscopy suite, or in the operating room. In addition to the PEG tube kit, an endoscopy cart is needed to perform the procedure percutaneously.

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Indications

Dysphagia is defined as abnormal or incomplete passage of enteral intake during swallowing. Significant dysphagia is the primary reason a percutaneous endoscopic gastrostomy tube placement is required. There are a variety of reasons patients might have significant dysphagia, some of which are short term and others which are more permanent.

Dysphagia is categorized as two different etiologies: oropharyngeal dysphagia and esophageal dysphagia. Oropharyngeal dysphagia is due to neuromuscular causes. This is due to lack of control of nerves that innervated the muscles of the mouth and pharynx. Many patients with profound critically illness and altered mental status will have persistent oropharyngeal dysphagia requiring established feeding access.

Patients with neurologic conditions and psychomotor delays will often need feeding access given functional dysphagia. Patients with severe dementia, cerebrovascular disease, comatose states, and traumatic brain injury may require short- or long-term feeding access variably based on their clinical condition [1].

Less commonly dysphagia occurs due to structural causes, known as esophageal dysphagia. These processes compromise the esophageal lumen. They can be related to benign or metastatic etiologies [1].

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Some patients with head and neck cancers may require feeding access due to tumor burden or after resection and reconstruction of their cancers. This can be required for long term for many patients. Esophageal cancer patients additionally whose esophagus is not able to pass enteral nutrition will require feeding access either in the stomach or small bowel.

Occasionally gastrostomy tubes are placed for purposes other than feeding. For instance, patients may require placement of a gastrostomy tube to vent the stomach in cases where there is either a real or functional obstruction.

Contraindications

There are several considerations that should be made prior to placement of a PEG tube which will increase the risk of complications with tube placement.

Relative risks include patient with coagulopathy and hemodynamic instability. Often these should be corrected prior to proceeding with the procedure. Additional contraindications include ascites, peritonitis, carcinomatosis, history of gastrectomy, interposed organs, and in cases where consent is not obtained or discussions have not been had regarding the goals of care [1].

Ascites can increase the technical difficulty of placing a PEG tube as well as increase the post-procedural risks. The presence of ascites can make transillumination of the abdomen difficult, if not impossible. In addition to technical difficulty, it can prevent proper apposition of the stomach to the abdominal wall, not allowing proper healing of the PEG tract. Risk for infection is also significantly increased given the potential to contaminate peritoneal fluid with gastric contents.

Portal hypertension and gastric varices are also considered relative contraindications to PEG tube placement. In addition to varices, collateral vessels can develop subcutaneously which will increase bleeding risk at the time of PEG insertion. Proper preprocedural planning including imaging review and physical exam is essential to prevent potentially morbid complications of PEG placement with advanced liver disease.

Risks/Benefits

Risk of Sedation

Patients will require sedation and analgesia for the procedure. Paralytic dosing may be required. These medications can induce hemodynamic instability. This may require administration of fluid resuscitation or vasopressor support. Generally hemodynamic changes should be brief, but in unstable patients or patient with significant cardiac or neurologic illness, increased risk is possible.

For moderate and deep sedation, serial monitoring of hemodynamics should be performed for the duration of the procedure. This should include frequent trending of heart rate, blood pressure, respiratory rate, and oxygen saturation. Any changes in hemodynamics should be treated promptly and appropriately [2].

Risk of Endoscopy

Patients with coagulopathy have an increased risk of bleeding during the endoscopy procedure. Bleeding can occur in the gastrointestinal tract from physical trauma to the esophagus and stomach. Additionally, bleeding can also occur from the PEG tube placement.

There is a small risk of perforation associated with upper endoscopy which can be clinically very significant. Esophageal perforation can cause significant inflammatory and infectious complications.

Risk of Aspiration

Placement of the endoscope into the mouth with advancement through the esophagus can pose a risk of aspiration to the patient who is awake and able to gag during the procedure. For this reason,

patients are often sedated and paralyzed for completion of the procedure. As the endoscope passed into the stomach, the lower esophageal sphincter is opened, making the reflux of gastric contents more likely.

Additionally, not making the patient NPO prior to the procedure can increase the volume of contents that could potentially be aspirated. Once the endoscope is advanced into the stomach, residual gastric contents and enteral nutrition should be removed with suctioning through the endoscope. This will prevent aspiration events and also optimize site selection for tube placement.

Risk of Procedure

Placement of the PEG tube has several potential procedures, some of which can be life-threatening. Many of these are discussed in the section regarding complications. Immediate complications related to the PEG tube itself during the procedure include risk of bleeding, risk of damaging the surrounding organs and structures, and risk of PEG tube dislodgement. Appropriate planning and review of the patient's anatomy, including any existing abdominal imaging, can help decrease the incidence of complications. Some preexisting conditions and history may preclude the patient from having the tube placed endoscopically and may require alternate surgical feeding tube placement options. These can include but are not limited to a laparoscopic gastrostomy tube, open gastrostomy tube placement, or jejunostomy tube placement.

When placing the PEG tube, it is essential to avoid the immediate dislodgement of the tube by pulling the tube too hard when placing the bumper on the tube. The bumper manipulation down the tube requires force, but care should be used to pull directly on the indwelling feeding tube so as to not pull the bumper through the abdominal wall. The endoscope should remain in place for the duration of the PEG placement to give direct visualization and ensure this does not occur.

Preparation

When performing a PEG tube at the bedside, planning is essential. The provider must coordinate equipment availability and nursing and respiratory therapy support to perform sedation needed for the procedure. The patient will require endotracheal intubation to control the airway during the procedure. Typically, if a PEG placement is being performed for a critically ill patient, a tracheostomy is performed in conjunction with this.

The optimal positioning for the procedure is in the supine position. Sometimes it is preferred for the head of bed to be slightly elevated. Having the head of bed elevated 30 degrees will encourage the stomach to be in the optimal anterior position to facilitate placement.

Sedation and analgesia should be provided for the patient prior to the initiation of the procedure. Vital signs should be monitored to ensure appropriate sedation is obtained. Often a paralytic is administered prior to starting the procedure. Vital signs should be assessed and documented frequently by nursing staff for the duration of the procedure [3].

For the PEG tube placement, endoscopy is necessary to facilitate placement. In many institutions this equipment must be checked out from the GI endoscopy suite or the operating room. In addition to the endoscopy cart, a commercially prepared PEG tube kit is obtained. There are several sizes of PEG kits and several methods for placement. A 24 French pull PEG tube kit is most commonly used in the adult patient in the critical care setting (Figs. 29.1, 29.2, and 29.3).

In addition to the PEG cart and kit, the provider should obtain appropriate asepsis supplies including appropriate PPE and sterile gloves. Skin prep of choice is necessary and occasionally excess body hair should be removed to optimize placement of the PEG tube. A bite block is often required to place in the patient's mouth prior to insertion of the endoscope.

Fig. 29.1 Endoscope

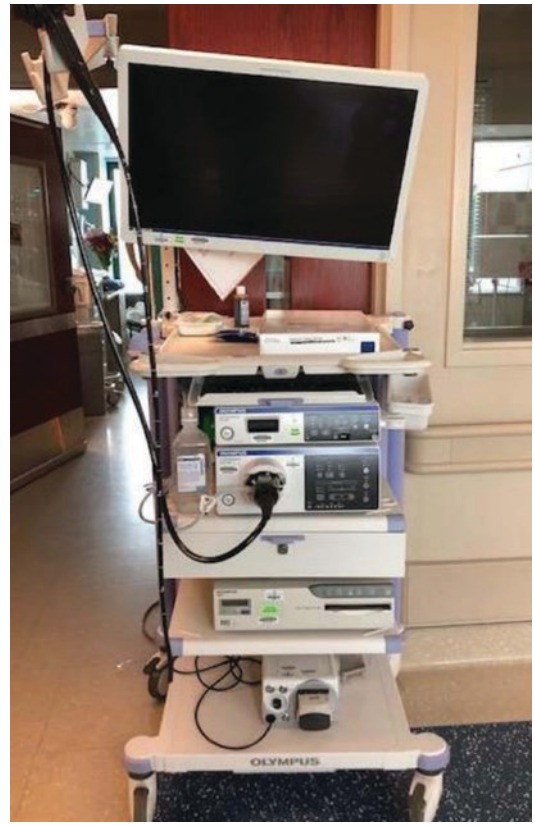

Fig. 29.2 Endoscopy cart

Procedure

1. Obtain informed consent.
   Consent should include the indications for the procedure, a brief review of the procedure to be performed, and the potential risks associated with the procedure.
2. Obtain necessary supplies including endoscopy cart, PEG tube kit, and asepsis supplies (Figs. 29.1, 29.2, and 29.3).
3. Perform time-out
4. Give appropriate sedation, analgesia, and paralytic as needed
5. Insert endoscope into the mouth, advance to the stomach, and inspect the stomach and first portion of duodenum

Fig. 29.3 PEG kit – 24 Fr pull

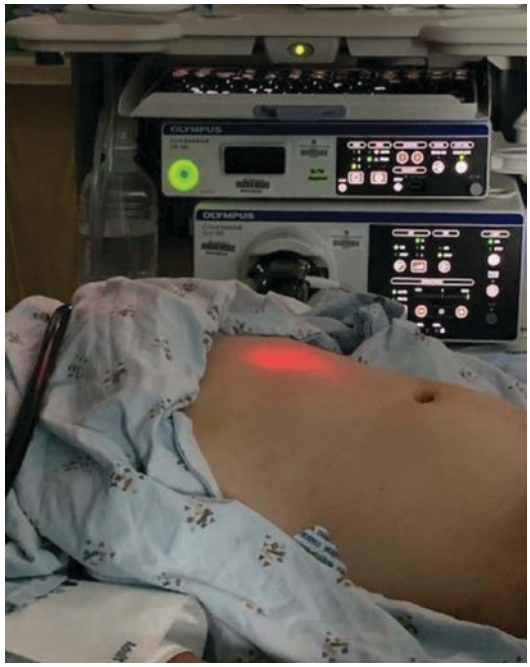

Fig. 29.4 Abdominal wall transillumination

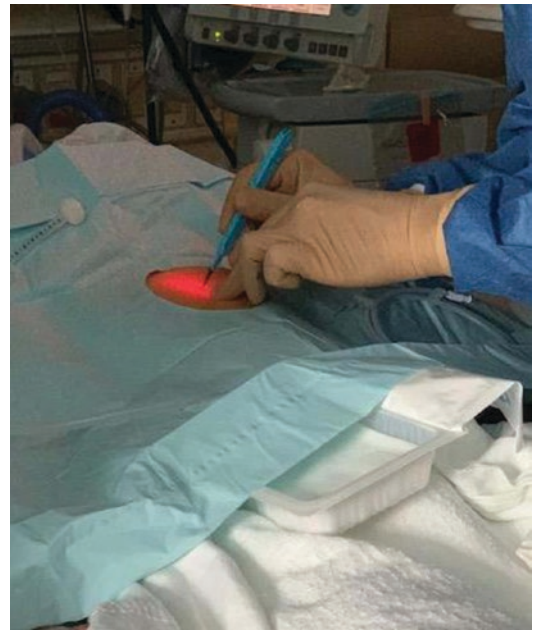

Fig. 29.5 Skin incision in abdominal wall

6. Insufflate the stomach and transilluminate
7. Identify transillumination on patient's abdominal wall, ensure adequate to proceed (Fig. 29.4)
8. Prep and drape patient's abdomen (second provider)
9. Advance snare through endoscope.
10. Make skin incision on abdominal surface at point of light reflection (second provider) (Fig. 29.5)
11. Insert needle and aspirating syringe as advancing (second provider)
12. Visualize needle entering the stomach with endoscope (Fig. 29.6)
13. Remove needle, leaving catheter in place, and advance wire through catheter (second provider)
14. Grab wire with snare, and pull wire back through esophagus and mouth with endoscope
15. Remove catheter, leaving wire in place (second provider)

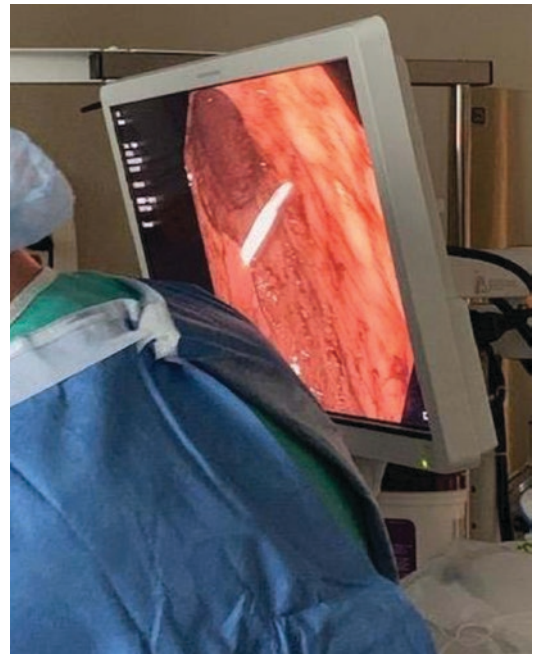

Fig. 29.6 Visualize needle entering stomach

Fig. 29.7 Pull wire through abdominal wall

16. Attach PEG tube to wire, then attach endoscope to balloon end of PEG tube
17. Pull wire through the abdominal wall (allowing first provider to follow with endoscopy), will require some force as PEG pulls through abdominal wall (second provider) (Fig. 29.7)
18. Follow PEG tube through esophagus into the stomach, visualizing placement in the stomach; remove wire
19. Pull up PEG flush with abdominal wall, rotate, and assist with wire removal (second provider) (Fig. 29.8)
20. Place bumper on outside of PEG (use caution not to pull through the stomach) (second provider) (Fig. 29.9)
21. Place clamp on outside of PEG (second provider)
22. Cut appropriate length of tubing from PEG tube (second provider)
23. Place stopper on end of PEG tube, and ensure stomach decompression (second provider) (Fig. 29.10)

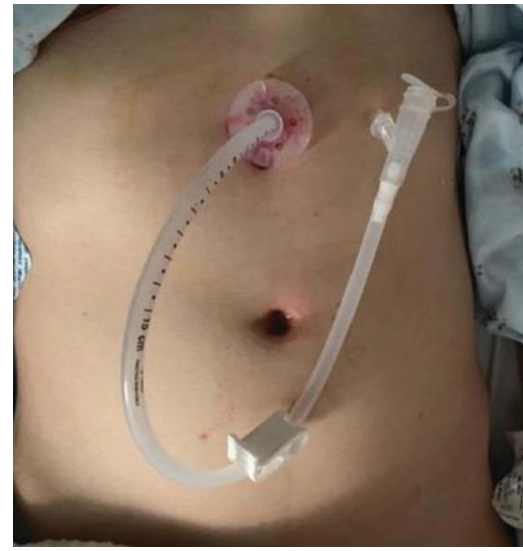

Fig. 29.8 Pull PEG flush with abdominal wall

Fig. 29.9 Place bumper on PEG tube

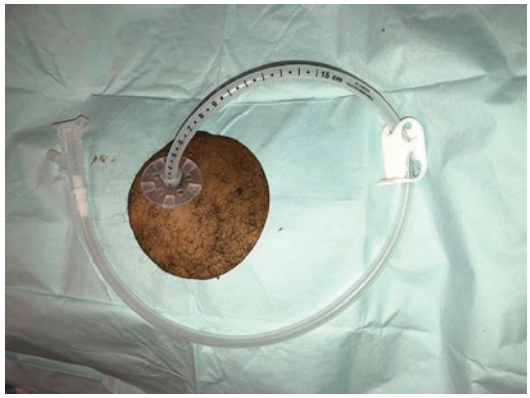

Fig. 29.10 PEG tube in place

24. Remove endoscope
25. Place PEG to drainage bag, and apply binder

Complications

Complications occur associated with PEG tube placement both in the acute and chronic maintenance of the tube placement. Some complications can be relatively minor and easily managed, while others can be life-threatening.

Skin Infections

Local skin irritation and infection can occur from leakage of gastric contents through the PEG tract or from irritation of the abdominal wall from recurrent strain on the PEG tube. Peristomal wound infections, while common, are often minor. Excess pressure between the bolster and the abdominal wall is a complicating factor. It is important to maintain position of the bumper and keep the insertion site free of tension to prevent increased risk. If the infection is significant enough to require treatment, a first-generation cephalosporin or quinolone is often enough [4].

Injury to the Surrounding Organs

Placement of the PEG tube has several potential procedures, some of which can be life-threatening. One potentially life-threatening immediate complication from PEG placement is damage of the surrounding structures. Percutaneous feeding placement relies on the ability to visualize the light reflex through the abdominal wall. This indicates that other intraabdominal structures are not lying between the stomach and the abdominal wall. The most common surrounding structure injured during PEG placement is the colon. The colon can lie anterior to the stomach and if decompressed can be transected before the feeding tube enters the stomach itself.

It is important to review any existing abdominal imaging in preprocedural planning to ensure anatomy is amenable to placement as well as ascertain previous surgical history to ensure the patient has an accessible stomach for placement. Procedures like a partial gastrectomy or upper GI resection and reconstruction will often require more advanced surgical planning and may preclude feeding access placement [5].

As previously discussed care should be taken to avoid injury to the surrounding intraabdominal organs.

Intraabdominal Infection/Accidental Dislodgment

After initial placement of the PEG tube, several complications can occur in its maintenance. One potential complication is inadvertent tube dislodgement. This can occur any time after tube placement either inadvertently from routine patient care or from patient removal. After placement some potential steps to avoid tube dislodgement include suturing of the bumper to the abdominal wall and placement of a binder around the abdominal wall. The binder acts as a barrier to prevent patient inadvertent removal and to blunt pulling on the PEG tube [6].

Leakage of gastric contents and enteral nutrition into the abdomen can be potentially life-threatening to the patient and cause severe infection. This most commonly occurs in the first 7 days after placement because the gastrocutaneous tract is not yet established. This will often require return to the operating room to wash out

the intraabdominal contents and may require gastric repair. Theoretically after the first week, the tract should be well healed, and unintentional removal of the tube can be more easily handled by replacing the tube and imaging the tube replacement [7].

Bleeding

Bleeding during a PEG tube placement can range from minor to life-threatening. Sources of bleeding are related to PEG placement, local vessel injury at skin level, and mucosal tear in the upper GI tract [2]. These minor bleeds can often be supported with the application of pressure to the site. Additionally, if any underlying coagulopathy exists, correction of this may improve bleeding.

More significant bleeding includes bleeding from a gastric artery and bleeding from a splenic or mesenteric vein. This can cause massive intraabdominal and retroperitoneal bleeding and may require additional intervention to achieve bleeding control. Resuscitation in these situations should include standard hemorrhage control resuscitation and attempts to identify and control the bleeding source [4].

Patient anticoagulation and any underlying coagulopathic conditions should be considered in the preoperative workup. Additionally, patients with severe gastritis, ulcerative disease, and active GI bleeding are commonly not appropriate for PEG placement until these conditions have been stabilized [8].

Buried Bumper Syndrome

Buried bumper syndrome is a severe complication associated with PEG tube placement. This occurs when the internal fixation device migrates along the tract of the stoma outside of the stomach. Excessive compression of tissue between the external and internal fixation device is the main cause of this complication. The incidence of buried bumper syndrome is approximately 1% [9].

BBS can be complicated by gastrointestinal bleeding, perforation, peritonitis, intraabdominal and abdominal wall abscesses, or phlegmon, and these complications can lead to fatal outcomes. Leakage of gastric contents or feeding, erythema, purulence, and pain are symptoms of local infection. The internal bumper can sometimes be palpable below the skin surface.

CPT Coding

49440 Insertion of gastrostomy tube, percutaneous, under fluoroscopic guidance including contrast injection(s), image documentation and report

49441 Insertion of duodenostomy or jejunostomy tube, percutaneous, under fluoroscopic guidance including contrast injection(s), image documentation and report

49442 Insertion of cecostomy or other colonic tube, percutaneous, under fluoroscopic guidance including contrast injection(s), image documentation and report

Summary

Long-term feeding access is necessary for the nutritional support of patients with dysphagia for a variety of reasons. An endoscopic approach to feeding access placement, the PEG tube, is commonly performed for these patients to provide their enteral support beyond the short course of their critical illness. The process of placing a PEG tube can have significant complications, and care should be done to minimize these both in the pre-procedural planning and post-procedural management of the PEG tube.

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Suggested Reading

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Additional Resources

Nursing care resources. https://www.nursingcenter.com/cearticle?an=00001610-201509000-00005&Journal_ID=54035&Issue_ID=3212367
Patient resources. https://gi.org/topics/percutaneous-endoscopic-gastrostomy-peg/

Paracentesis

30

Cindy Sing, Noelle McNaught,
and Bradley W. Thomas

Introduction

Paracentesis is a procedure that can be performed in clinic or at the bedside in which a needle is passed to remove fluid from the peritoneal cavity for diagnostic or therapeutic purposes [1]. Various conditions produce ascitic fluid. Normally, the peritoneal fluid is straw-colored. It can however, be a variety of colors and consistencies depending on the underlying disease process. The fluid is collected to relieve patient discomfort with refractory ascites and may also be analyzed to diagnose the cause of the ascites [2].

Indications

Abdominal paracentesis is performed in any patient with new-onset ascites to establish the etiology of the ascitic fluid. It is also performed when a patient with preexisting ascites is deteriorating, for symptomatic relief (Fig. 30.1a), or if spontaneous bacterial peritonitis (SBP) is suspected. Lastly, patients with tense or refractory ascites with hemodynamic instability should undergo paracentesis to decrease intra-abdominal and diaphragmatic pressures, as well as to ease dyspnea and respiratory compromise [3, 4].

Contraindications

Patients with liver disease undergoing paracentesis may have a baseline thrombocytopenia or coagulopathy. Because the prevalence of significant bleeding during paracentesis is low, use of platelets or fresh frozen plasma is not routinely recommended [5]. One absolute contraindication is when a patient has an acute surgical abdomen and exploration is required immediately. However, at times differentiating the acute surgical abdomen from SBP can be challenging. Paracentesis should be avoided in patients with clinically evident disseminated intravascular coagulation or clinically evident primary fibrinolysis. Other relative contraindications include patients with severe bowel distention (use ultrasound in this case), patients with previous abdominal surgery (needle should be inserted several centimeters from scar), patients who are pregnant, and patients with distended bladder (especially if it cannot be relieved with a Foley catheter) and cellulitis or abscess at the intended

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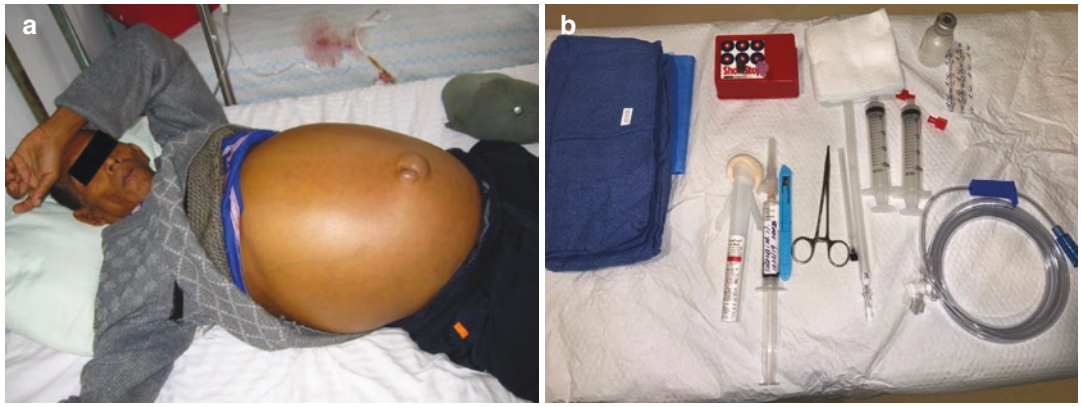

Fig. 30.1 (**a**) Patient with ascites, (**b**) preassembled package kit

site of insertion [3, 4]. Also avoid inserting the needle through visibly engorged subcutaneous veins or hematomas in the abdominal wall [5].

Risks/Benefits

Risks of withdrawing peritoneal fluid include pain, discomfort, bowel or bladder perforation, ascitic fluid leak, pulmonary edema, infecting sterile ascites, bleeding, decrease circulating volume leading to hypotension and/or renal insufficiency, dysrhythmias, and mortality [2].

Benefits include decreased work of breathing, relief of abdominal pain or discomfort, determination of ascitic fluid etiology, and diagnosis of suspected infection [2].

Table 30.1 Equipment required

Sterile drape or towels
Sterile gloves, mask, gown
Skin cleansing agent
Sterile gauze
Skin marking pen
Lidocaine 1% or 2%
60 mL syringe (not shown) for cytology
20 mL syringe × 2
10 mL syringe (for lidocaine)
1.5-inch 22-gauge and 1-inch 25-gauge needle
Vacuum bottles or suction canisters
Sharps receptacle box
#11 blade scalpel
Suction tubing (for therapeutic thoracentesis)
Paracentesis needle
Hemostat (for optional tube clamping)

Preparation

Before beginning, explain the procedure to the patient, ensure they understand risks and benefits, and obtain written informed consent [2]. Again, detailing risks which include persistent ascitic fluid leak, pulmonary edema, hypotension, bowel injury, bleeding, infecting sterile ascites, and mortality. Fasting is not necessary and should not delay this procedure. Gather all necessary equipment (Table 30.1), most of which is included in preassembled kits (see Fig. 30.1b), prepare any laboratory paperwork, and write/enter orders for the ascitic fluid tests (if diagnostic paracentesis) prior to the procedure to increase efficiency [3]. In non-emergent cases, perform a pre-procedure verification and time-out [2].

Needle Choice

Selection of needle is dependent on whether a therapeutic or diagnostic paracentesis is being performed. For diagnostic paracentesis, a 1.5-inch 22-gauge needle can be used in a thin patient and a 3.5 inch 22-gauge needle for obese patients. Therapeutic paracentesis generally employs larger gauge needles, for example, Caldwell needles or catheter over needle (Yueh needle seen in

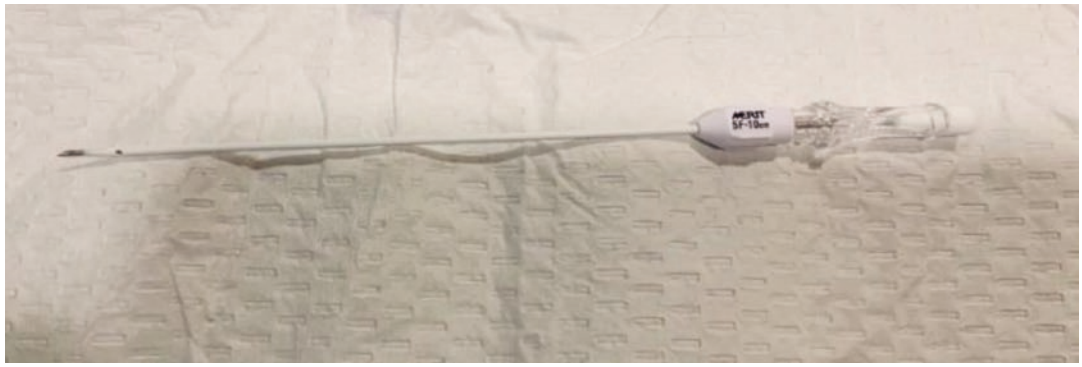

Fig. 30.2 Example of 5Fr 10 cm Yueh needle

Fig. 30.2) [3]. This allows for more rapid removal of larger volumes of fluid.

Patient Position

Patient should be positioned supine with a slight elevation of the head. Patient can be slightly tilted to the side of fluid collection to help with pooling as fluid accumulates in dependent areas [2].

Determine Site for Needle Insertion

Typically, the right or left lower quadrants are preferred sites. The puncture site should be lateral to the rectus sheath to avoid injury to the inferior epigastric artery. This is two finger widths from the umbilicus to the anterior iliac crest. The midline or sub-umbilical approach can also be utilized, but the bladder must be emptied prior to using this location. If this site is used, stay midline 2–3 cm below the umbilicus. This site is technically more challenging for obese patients. Examine the abdomen for areas of shifting dullness, which indicate fluid. Ultrasound guidance is commonly employed to confirm the presence of fluid and may add a margin of safety. Ultrasounds can assist in avoiding bowel, bladder, or other organs within the range of the needle (Fig. 30.3a). The probe used to find an adequate pocket of fluid is the phase array probe. Measuring

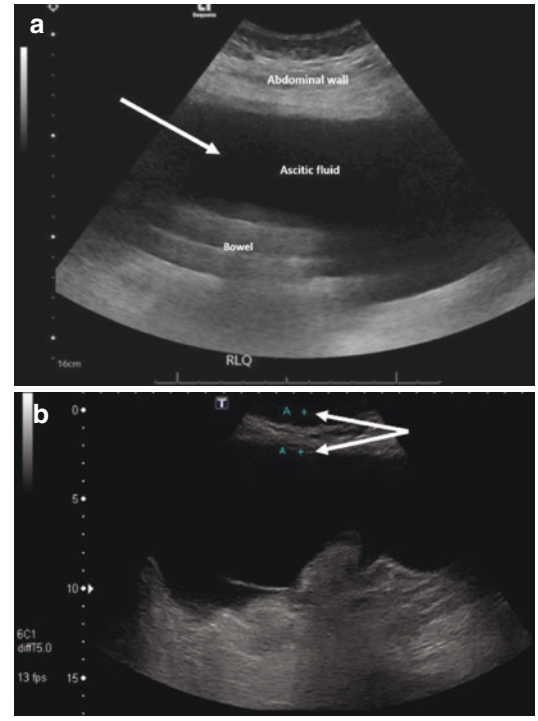

Fig. 30.3 (**a**) Ultrasound image showing abdominal wall and bowel with arrow pointing to ascitic fluid. (**b**) Arrows showing measurement of the abdominal wall thickness

the abdominal wall thickness can be performed to the determining the depth of the puncture (Fig. 30.3b) [6]. To avoid unforeseen vasculature, the line probe can be used. Mark the needle insertion site with a surgical marker once the suitable site is found [2–5].

Procedure

Site Preparation

Preparing the site can be done with non-sterile gloves using chlorhexidine-alcohol or betadine solution applied in a circular motion starting at the needle entry site and moving outward (Fig. 30.4a). Once sterile gloves and gown are donned, a drape or sterile towels are then placed, outlining the insertion site [4].

Anesthetizing the Site

Anesthetize the subcutaneous area using a 1-inch 25-gauge needle with 1% lidocaine, preferably with epinephrine to help eliminate or decrease abdominal wall bleeding and make a small wheal. Draw up the remainder of the lidocaine in a 10 mL syringe and a 22-gauge needle to anesthetize the deeper tissue. Advance the needle ½ cm at a time, while simultaneously aspirating back on the syringe until a flash of ascites is encountered, which allows the provider to know immediately when the peritoneal cavity is entered. Once you have entered the peritoneum, slowly inject the remaining lidocaine as you back out of the tract. Allow for generous administration (our facility uses a full 10 lidocaine) and let set in for at least 30 seconds. This method maximizes the ability to adequately anesthetize the highly sensitive parietal peritoneum (Fig. 30.4b, c) [3, 4].

We typically do not make a skin nick with a scalpel. It is usually unnecessary and may lead to post procedure leakage; however, some providers do opt for it, as it may add to easier catheter insertion.

Entering the Abdominal Wall, Z-Track Technique

In both therapeutic and diagnostic paracentesis, a Z-track technique has been purported to decrease the incidence of ascitic leak following the procedure. This technique involves pulling the skin down while inserting the needle. The retraction on the skin is not released until the ascites fills the syringe. In our institution we have moved away from this technique as it tends to be painful to the patient and distorts trajectory, and we rarely encounter leakage post procedure without using Z-track technique.

Paracentesis Procedure

After the area is anesthetized, (optionally) use a #11 blade, and make a skin puncture large enough to allow entering of the paracentesis catheter. The Yueh catheter is then attached to a 10 mL syringe (Fig. 30.4d). Advance the catheter into the tissue at a 90-degree angle to the skin while simultaneously aspirating back on the plunger. Once the needle is advanced into the peritoneal cavity and ascitic fluid begins to fill the syringe, stop advancing the needle (Fig. 30.4e). Real-time ultrasound can be used to guide needle and confirm proper placement if needed (Fig. 30.5). Guide the catheter over the needle into the peritoneal cavity, and then remove the needle. After advancing the catheter, a three-way stop cock with suction tubing can then be attached to the hub of the catheter, which allows for easy and less messy collection of ascites in 20–60 mL syringes for laboratory testing if needed (Fig. 30.6). Next connect the suction tubing to vacuum bottles or wall suction catheters and canister (Fig. 30.7).

Large Volume Therapeutic Paracentesis

A large volume paracentesis occurs if 5 L or more of ascitic fluid is removed. Large volume paracenteses are done for those patients with refractory ascites to extend the interval to the next paracentesis. One liter of peritoneal fluid is equivalent to approximately two pounds of weight. Removing a large volume may cause hypotension or even acute kidney injury due to fluid shifts and intravascular volume depletion. Some patient may also develop adhesions or loculations in the peritoneal cavity, which may occlude the catheter and stop flow. The bowel and

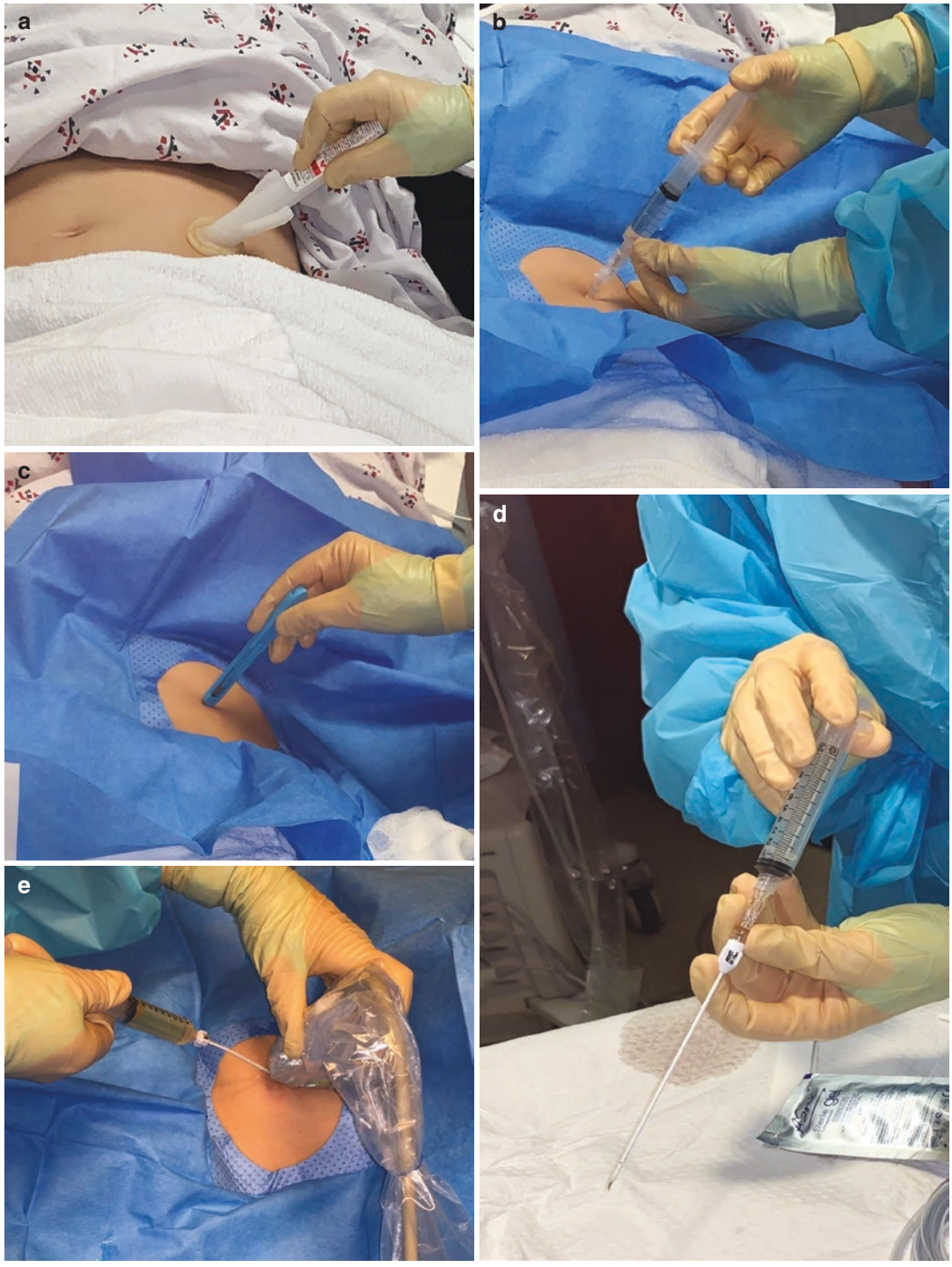

Fig. 30.4 (**a**) Marked entry site as indicated with x and site preparation in circular motion [7]. (**b**) Place sterile drape and make a wheal and anesthetize the deeper tissue [7]. (**c**) Optional skin nick with #11 blade. (**d**) 5 French 10 cm Yueh catheter attached to 10 mL luer lock syringe. (**e**) Real-time ultrasound guidance utilized for catheter insertion into the peritoneal cavity

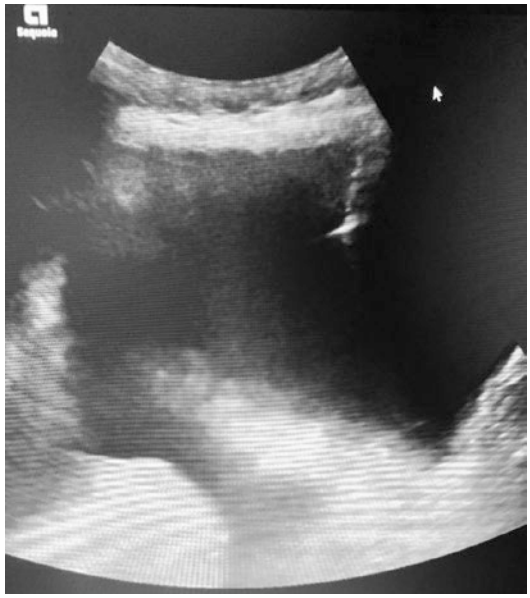

Fig. 30.5 Arrow pointing to needle tip in ascites, carefully avoiding the bowel and liver

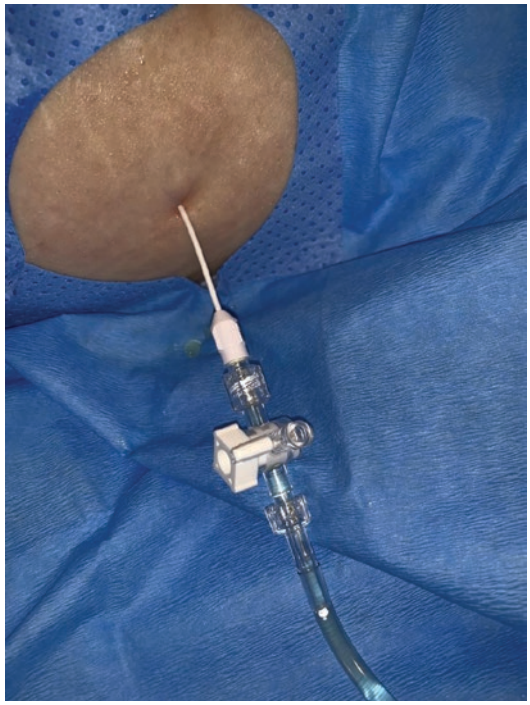

Fig. 30.6 Catheter attached to three-way stop cock and suction tubing. Note the side port, which allows for syringe aspiration for lab testing

Fig. 30.7 Ascites flowing into collection canister attached to wall suction

omentum commonly do this as drainage continues and intra-abdominal ascites volume decreases. There are several "troubleshooting" techniques that can be deployed, such as patient reposition or having an assistant gently apply pressure in a sweeping motion across the abdomen toward catheter insertion site while avoiding the sterile field. Another way to obtain more fluid is to stop suction with a three-way valve attached to the catheter and pull the catheter slightly back until flow is encountered again. If this fails, a sterile saline syringe may be attached to the open three-way stop cock, firmly flushing the catheter, which "pushes" the bowel off the catheter tip, thus restoring an unobstructed flow (Fig. 30.8).

After the fluid is removed, gently remove the catheter and apply pressure to the entry site. If the site is still leaking fluid after 5 minutes of direct pressure, a pressure dressing may be required. The patient may need to lie flat for 2 hours with the paracentesis site up to help reduce leakage

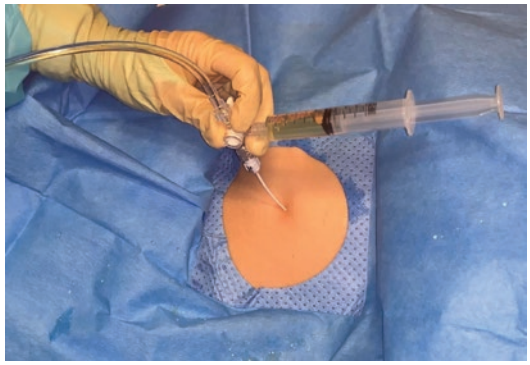

Fig. 30.8 Troubleshooting technique utilizing three-way stop cock

from the site. If leakage persists, suture the puncture site with the purse string suture. If significant leakage is encountered, apply a stoma bag over the site until drainage has become minimal. Dermabond can be effective, so long as the leak is not a constant steady stream of ascites.

Albumin After Large Volume Paracentesis

Albumin replacement is somewhat controversial but remains recommended for large volume paracentesis of 5 L or more to prevent hepatorenal syndrome. Dosing recommendation is albumin 25% 8–10 g per L of ascitic fluid removed [4].

Diagnostic Paracentesis

Diagnostic paracentesis requires advancement of a 20 mL syringe along the same track as the anesthetic needle, intermittently pulling back and using ultrasound to confirm proper placement until ascites is aspirated. Collecting at least 20 mL of ascites is likely enough for the tests needed for a diagnostic paracentesis. For obese patients, use a 3.5 inch 22-gauge needle. It is particularly important for safety to utilize direct visualization of the needle with ultrasound of small fluid collections. For initial diagnostic paracenteses, cytology is usually sent. If so, most of the laboratories require at least 100 mL of fluid for the initial diagnostic paracentesis; however, defer to your institution's requirements.

Peritoneal Fluid Analysis

Examine the fluid's gross appearance. Turbid fluid can indicate infection or tumor cells. Milky white fluid could represent chylous ascites if triglycerides are >200 mg/dl [1]. Common tests include albumin, amylase, lactate dehydrogenase, glucose, total protein, and culture. Aspirated fluid should generally be immediately placed into appropriate specimen tubes. Learn your specific institution policy for any variation. Typically, an EDTA tube is sent for cell count and differential evaluation. A tube without additives is sent for total protein and albumin concentration. When SBP or infection is suspected, inoculate blood culture bottles at the bedside to maximize the yield and use aseptic technique. A positive test for SBP is indicated by an absolute neutrophil count of 250 cells/uL. It may not be necessary testing cell count with each repeated paracentesis when performed outpatient but may be useful to diagnose occult SBP. However, it is recommended to send a cell count on every hospitalized patient. Other special tests like mycobacterial culture, cytology, bilirubin, and triglycerides are not only sent depending on the clinical scenario [1, 3].

Algorithm for Diagnosis of Ascites

Serum albumin level should be sent simultaneously for calculation of the serum-ascites albumin gradient (SAAG), used to distinguish from portal and non-portal hypertensive ascites. A SAAG ≥1 g/dL reflects portal hypertension. A SAAG <1.1 g/dL is indicative of ascites not related to portal hypertension. Further analyze ascitic protein level as indicated in Fig. 30.9 for more specific diagnosis [1].

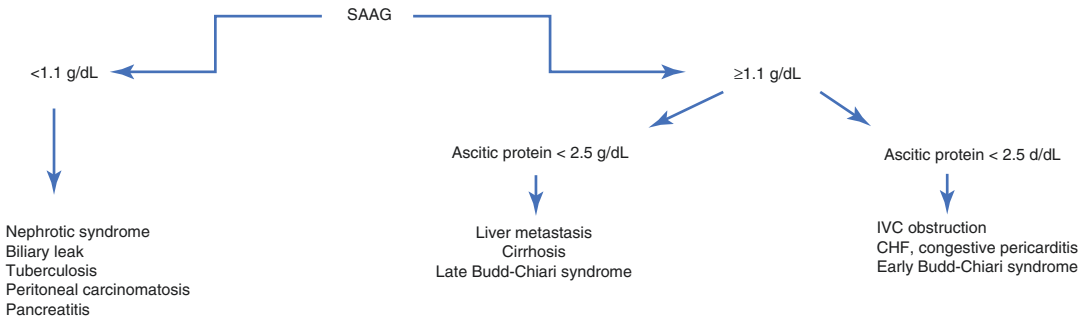

Fig. 30.9 Algorithm for the diagnosis of ascites

Complications

Paracentesis generally is regarded as a safe procedure. However, the most described complications include bleeding, infection, organ perforation, ascitic fluid leak, and very rarely death. Puncturing of a vessel or variceal in patients that commonly have significant portal hypertension can be fatal, and infrequently, a laparotomy or arteriogram with embolization may be needed for hemorrhage control. Serious bleeding risk is increased in those patients with clinically evident fibrinolysis or renal failure. Bowel injuries secondary to the paracentesis needle can result in infection or more serious complications. Small bowel injury from this procedure does not usually lead to peritonitis, is typically well tolerated, and treatment is not required unless infectious symptoms develop [4].

Ascitic fluid leak from the puncture site is a common complication, particularly if a large skin incision was made or a large bore needle was used. The Z-track technique can help reduce this by creating a non-linear tract. If leak does occur, the use of an ostomy bag over the leak site can help quantify the amount of fluid leaking. Avoid gauze dressings as they typically saturate with fluid and can lead to skin breakdown and possible cellulitis. Other helpful measures include laying patient on opposite side, applying direct firm pressure to the area, possibly repeating a large volume paracentesis or applying a suture at the puncture site [3, 4].

After large volume paracentesis, hypotension and hepatorenal syndrome can occur. Hypotension typically responds to albumin or crystalloid fluid boluses.

Keys to Success, Perils and Pitfalls

- Straight forward procedures that can be done in the clinic or bedside.
- In appropriately selected patients, paracentesis is both a powerful diagnostic and therapeutic tool.
- A closed system should always be used when performing paracentesis to reduce infection risk.
- Proper technique can reduce the risk of ascites leak.
- Ultrasound guidance can be of assistance, particularly for smaller fluid collections.
- An elevated INR or thrombocytopenia generally should not be treated/transfused to normalize for this procedure.

CPT Coding

Ascites R18.8
History of ascites Z 87.898
Cirrhosis K74.60
Cirrhosis of the liver with ascites K74.60
Spontaneous bacterial peritonitis K65.2
History of SBP Z86.19
Family history of SBP Z83.1

Summary

Abdominal paracentesis is a procedure commonly performed in those with advanced liver disease or patients with metastatic cancer, such as ovarian cancer. It helps diagnose the cause of the ascitic fluid, and it relieves symptoms of abdominal fullness, discomfort, or dyspnea. To avoid unexpected outcomes it is important to know the anatomy of the abdomen, use ultrasound guidance when indicated and to follow the appropriate procedural steps.

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Additional Resources

https://www.youtube.com/watch?v=_r7MaXw1CFw
https://www.youtube.com/watch?v=9npNQM8ANds

Abdominal Compartment Syndrome

31

Elizabeth R. Peitzman, Michael A. Pisa, and Niels D. Martin

Background

Abdominal compartment syndrome (ACS) was first suggested by Marey in 1863 although the term intra-abdominal compartment syndrome was not introduced until 1989 [1–2]. Further, it was not recognized widely as a distinct process until the last few decades [3]. Within the past two decades, attempts to standardize terms and treatment have started [3]. The World Society of Abdominal Compartment Syndrome (WSACS) was created due to the increased attention to ACS. WSACS published consensus definitions in 2006 followed by clinical practice guidelines in 2007. Both were updated in 2013 [4].

Definitions

Intra-abdominal pressure (IAP) is the steady-state pressure within the abdominal cavity measured at end expiration with fully relaxed abdominal wall musculature [2, 4–6]. Biomechanically, as it pertains to IAP and ACS, the abdomen is a closed anatomic space with partially compliant borders (the diaphragm and the abdominal wall musculature) [3]. IAP is a reflection of the intra-abdominal volume and abdominal wall compliance. As abdominal distension increases, abdominal compliance decreases [7]. Normal IAP ranges from 0 to 15 mm Hg [5]. It is approximately 5–7 mmHg in critically ill adults [4, 5, 8] and slightly higher in the obese [3]. There is a subset of non-obese, non-critically ill adults, inclusive of the pregnant or those with chronic ascites, where IAP is chronically elevated [3]. After uncomplicated abdominal surgery in non-critically ill adults, IAP may be transiently elevated to levels between 3 and 15 mmHg [3, 9].

Intra-abdominal hypertension (IAH) is defined as the sustained or repeated intra-abdominal pressure (IAP) $\geq$ 12 mm Hg [2, 5, 10] (Table 31.1). The grading system for IAH is as follows:

When IAH is sustained or repeatedly elevated to levels $\geq$20 mmHg and associated with new organ dysfunction, it is referred to as abdominal compartment syndrome (ACS) [4, 5, 10]. Both IAH and ACS are further categorized into primary, secondary, or recurrent. Primary IAH or ACS results from injury or disease in the abdominopelvic region. Frequently, this requires early surgical or interventional radiological intervention as necessary in their treatment [2, 4, 5, 11]. In one study, primary IAH accounted for as many as 32% of patients with IAH [12]. Secondary IAH or ACS results from maladies outside the

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Table 31.1 Intra-abdominal Hypertension Grading System [1, 2, 4–6]

Grade	IAP (mmHg)
I	≥12–15
II	16–20
III	21–25
IV	>25

abdominopelvic region [2, 4, 5, 11], for example, following a massive resuscitation creating mesenteric edema to the degree that abdominal pressure is affected [13]. Recurrent IAH or ACS is the redevelopment of IAH or ACS following previous surgical or medical treatment of IAH/ACS [4]. It occurs in 20% of patients who have previously undergone surgical decompression [3].

Similar conceptually to cerebral perfusion pressure, abdominal perfusion pressure (APP) is equal to mean arterial pressure minus intra-abdominal pressure [2, 4, 8, 14]. APP can be used as a surrogate for visceral perfusion and can be used as a predictor of the need for surgical intervention and overall patient outcome [2, 6, 14]. An APP of less than 60 mmHg has been shown to reliably predict the necessity for surgical decompression [2]. In a retrospective study, an APP of at least 50 mmHg was found to be a better predictor of patient outcome than MAP, IAP, or other resuscitation endpoints (pH, base deficit, lactate, urine output) with a sensitivity of 76% and a specificity of 57% [14].

Prevalence

The prevalence of IAH ranges from 20% to 50% on ICU admission [10] and 10–35% in non-trauma critically ill patients [6]. In a few prospective studies, the prevalence of IAH on admission to ICU ranged from 30% to 34% with additional 15–33% developing IAH during ICU admission [12, 15, 16]. The presence of ACS on admission ranged from 2.7% to 6.3% [13, 16, 17]. The overall prevalence of ACS ranges from 5% to 50% [18]. Notably, there is no difference in IAH occurrence in comparison of medical versus surgical ICU patients [16, 17]. Likely owed to the emphasis on a more restrictive approach to volume resuscitation adopted over the past 10–15 years, the incidence of IAH and ACS appear to be decreasing [3, 19].

Morbidity/Mortality

Abdominal compartment syndrome is associated with high mortality. As IAH increases in grade, the associated mortality also increases [8–10]. IAH is an independent predictor of mortality [2, 17]. The mortality rate of ACS ranges from 43% to 83% [2, 12, 20]. In one prospective observational study, the mortality of ACS was 67.7% at 28 days and 75.9% at 90 days [16]. Without treatment, the mortality of ACS is greater than 90% [21].

Risk Factors

In general, IAH is a result of decreased abdominal wall compliance, an increase in intra-abdominal volume, or a combination of the two [6]. Some conditions predisposing patients to developing IAH/ACS as well as risk factors are listed in Table 31.2 [12, 17, 22].

The predominant predisposing conditions for primary ACS are peritonitis, pancreatitis, and abdominal trauma [3]. Pancreatitis is an inflammatory process associated with capillary permeability and hypoalbuminemia. This can lead to significant intraperitoneal, retroperitoneal, and visceral edema which in turn contributes to the development of IAH and ACS [3]. The predominant predisposing condition for secondary ACS is extra-abdominal sepsis [21]. This may be attributed to aggressive fluid resuscitation, which is also an independent predictor of developing secondary ACS [7, 8]. In one study, independent predictors of IAH in a mixed ICU on hospital day 1 were liver dysfunction, abdominal surgery, fluid resuscitation with more than 3.5 L during 24 hours before inclusion, and ileus [11].

Table 31.2 IAH/ACS predisposing conditions and risk factors

Predisposing conditions	Risk factors
Previous abdominal surgery	Hypothermia
Abdominal infection	Acidosis
Massive fluid resuscitation	Anemia
Hypotension	Oliguria
Gastroparesis/ileus	Abdominal surgery
Acidosis	Abdominal trauma
Multiple transfusions	High volume fluid resuscitation (≥3.5 L in 24 hours)
Mechanical ventilation	Ileus
Pneumonia	Pulmonary dysfunction
Bacteremia	Renal dysfunction
Acute respiratory distress syndrome	Liver dysfunction

Decreased Abdominal Wall Compliance

Abdominal compliance is how easily the abdomen expands, which is determined by the elasticity of the abdominal wall and diaphragm [4]. A decrease in abdominal wall compliance can be caused by abdominal surgery, major trauma, abdominal wall edema, major burns, or prone positioning [4, 6]. Abdominal compliance is an important factor in predicting organ failure [3]. Among patients admitted to the ICU, those with burns over >60% of total body surface area, or with concurrent inhalational or intra-abdominal injuries, are at high risk for development of ACS [3].

Increased Intra-luminal Contents

Increased intra-luminal contents can be caused by gastroparesis, gastric distension, ileus, colonic pseudo-obstruction, and volvulus [4].

Increased Extra-luminal/Intra-abdominal Contents

Increased extra-luminal/intra-abdominal contents can be caused by acute pancreatitis, hemoperitoneum, pneumoperitoneum, intra-peritoneal fluid collections, intra-abdominal infection/abscess, intra-abdominal or retroperitoneal tumors, laparoscopy with excessive insufflation pressures, liver dysfunction/cirrhosis with ascites, or peritoneal dialysis [4]. Pregnancy may be associated with a state of chronic IAH. Complications of pregnancy, such as pre-eclampsia and HELLP syndrome, or abdominal ascites as a complication of ovarian hyperstimulation syndrome, may transition to ACS [3]. Another population specifically at risk for developing ACS are patients following either open or endovascular repair of ruptured abdominal aortic aneurysms. This is true even in the absence of bleeding. This is due to massive fluid resuscitation, hypothermia, and large space-filling retained hematomas in endovascular repairs [3].

Capillary Leak/Fluid Resuscitation

A positive fluid balance has a strong association with IAH and worse outcomes [10]. Risk factors for IAH/ACS relating to capillary leak/fluid resuscitation include acidosis, damage control laparotomy, hypothermia, increased APACHE-II or SOFA score, massive fluid resuscitation, positive fluid balance, and polytransfusion [3, 4, 6].

Other/Miscellaneous

Other factors that have been cited to contribute to IAH/ACS include age, bacteremia, coagulopathy, increased head of bed angle, massive incisional hernia repair, mechanical ventilation, obesity or increased body mass index, PEEP>10, peritonitis, pneumonia, sepsis, shock or hypotension, and disease severity (APACHEII) [4, 16].

Pathophysiology/Clinical Presentation

IAH affects the functioning of the major organ systems of the body either directly by compression or indirectly by generalized hypoperfusion

in setting of decreased cardiac output (CO) resulting from a degradation of venous return [23]. The direct compressive effect of IAP leads to reduced microcirculatory perfusion, which eventually overwhelms compensatory mechanisms of the affected organ system, eventually leading to organ dysfunction [5]. The localized oxygen deficit leads to capillary failure and leakage which further contributes to tissue edema and elevations in IAP [21]. If uncorrected, progression to IAH and eventual ACS is inevitable, leading to further degradation of microcirculatory perfusion, anaerobic metabolism, and acidosis. This acidosis is often further compounded by accompanying respiratory acidosis provoked by decreased thoracic cavity compliance resultant from an upwardly pressing diaphragm (Fig. 31.1) [6].

Cardiovascular System

Overall in the CV system, a net decrease in CO leads to hypotension [6, 24, 25]. The cause is multifactorial. There is a decreased venous return caused by IVC compression [6, 9, 21, 25, 26]. There is also an increased intrathoracic pressure, which in turn causes decreased RV compliance and decreased cardiac filling [6, 25]. These effects are amplified by hypovolemia [6]. With high elevations in IAP, the aorta and splanchnic circulation are compressed leading to an increased SVR, increased afterload, and reduced stroke volume [6, 25]. Additionally, IAH reduces thoracic compliance which leads to increases in pulse pressure variation mimicking hypovolemia. This may lead to the inappropriate administration of fluids [3]. Notably, the

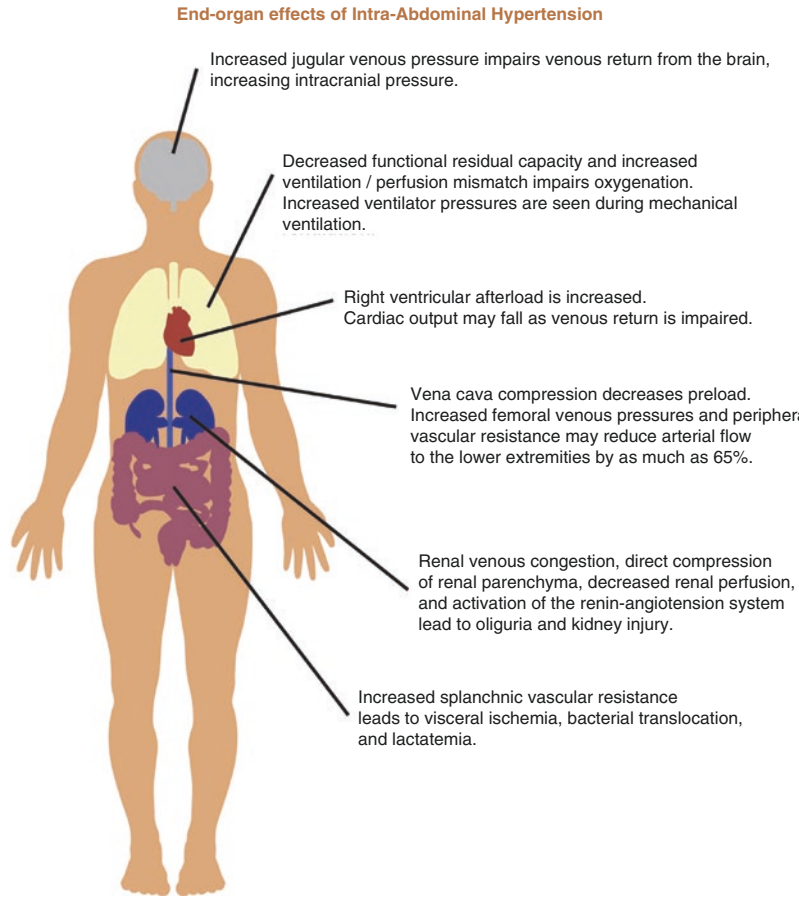

Fig. 31.1 End-organ effects of intra-abdominal hypertension. (Reprinted from Rogers and Garcia [3]. With permission from Elsevier)

pulmonary artery wedge pressure and central venous pressure are falsely elevated in IAH, not due to hypervolemia but due to increased intrathoracic pressure [2, 8, 27, 28].

Pulmonary

The effects of IAH/ACS on the pulmonary system caused by cephalad pressure on the diaphragm include decreased vital capacity, decreased functional residual capacity, and tidal volume [6, 11, 26]. Compression of the lungs leads to decreased pulmonary compliance [11, 25]. At an IAP of 16 mmHg, the pulmonary compliance decreases by 50% [2]. This decrease leads to a reduction in total lung capacity, functional residual capacity, and residual volume [25]. These combined effects may lead to hypoxemia and hypercapnia [6, 21]. This is due to alveolar atelectasis, increased alveolar dead space, and decreased pulmonary capillary flow. In this setting, both shunt and dead space physiology are demonstrated. If allowed to persist, hypercapnia and hypoxic respiratory failure will ensue [2, 6, 7]. Peak inspiratory, plateau, and mean airway pressures are all increased [2, 11, 26, 27].

Gastrointestinal

The effects of IAH/ACS on the GI system are numerous. Hepatic ischemia and impairment caused by portal vein and hepatic artery compression leads to decreased clearance of lactate [6]. A feedback loop is activated where lactic acidosis leads to systemic arteriolar dilation, which in turn leads to worsening hypotension and increased lactic acid production [6]. Further, ischemic effects on the liver activate Kupffer cells releasing inflammatory mediators acting on hepatocytes and sinusoidal cells [21].

Decreased mesenteric perfusion leads to bowel ischemia [6]. This is caused in part by capillary compression and decreased venous outflow from splanchnic circulation, leading to congestion and contributing to further decreased mesenteric perfusion [2, 6, 8, 21]. Decreased visceral perfusion is observed at IAP of as low as 15 mm Hg [11]. In animal models, at IAP of 20 or higher, there is a severe progressive decrease in mesenteric and mucosal blood flow [29]. At 20 mm Hg, mesenteric artery flow is decreased by 37% and at 40 mm Hg, and mesenteric artery flow is decreased by 69%. At 20 mm Hg, mucosal blood flow is at 61% of baseline. At 40 mmHg, it is 28% of baseline [29]. In a study of patients undergoing laparoscopy, a reduction of 11–54% in blood flow to the duodenum and stomach was observed at an IAP of 15 mmHg [11]. These effects can lead to bacterial translocation causing sepsis or septic shock [2, 6, 11]. In the postoperative population, decreased rectus muscle blood flow can lead to impaired abdominal wound healing, fascial dehiscence, and surgical site infection [25].

Renal

Renal dysfunction is one of the earliest clinical manifestations of IAH [5, 8, 18]. Oliguria occurs when IAP > 15 mmHg [6, 25]. Anuria occurs when IAP >30 mmHg [6]. The acute kidney injury that is observed in IAH/ACS is caused by both pre-renal and tubular processes [6]. Renal arteriole, renal vein, renal tubule, and IVC compression lead to alterations in glomerular blood flow and glomerular filtration rate (GFR) [6, 21, 26]. In an animal model, when IAP is increased from 0 to 20 mmHg, GFR is decreased by 25% [11]. Direct compression of the renal parenchyma causes impaired microvascular perfusion leading to worsening tubular ischemia [18]. Decreased GFR triggers increased activation of the renin-angiotensin-aldosterone cascade increasing SVR [6, 25]. Notably, the renal dysfunction associated with IAH is associated with diuretic resistance [18].

Central Nervous System

IAH affects the central nervous system as well. Sustained increased intra-abdominal and intrathoracic pressures are associated with increased intracranial pressure and decreased cerebral

perfusion pressure [2, 7, 9, 27]. The most profound effect of IAH is impeding cerebral venous outflow secondary to increased intrathoracic pressures and elevated central venous pressures.

Diagnosis

The median time from admission to suspicion of ACS in MICU versus SICU patients was 60 hours versus 13 hours [20]. The time from suspicion to surgical consultation for MICU versus SICU patients was 60 minutes versus 0 minutes [20]. Abdominal examinations are an unreliable predictor of IAP [7, 10]. As such, WSACS recommends screening for IAH/ACS with the objective measurement of IAP when 2 or more risk factors are present [2].

There are various methods by which to measure IAP. The transduction of bladder pressure is the preferred method for indirect measurement of IAP and is recommended by the WSACS as the standard IAP measurement technique (Figs. 31.2 and 31.3 & Table 31.3) [4, 21].

It should be noted that this technique has several limitations and pitfalls. IAP should be measured in supine position with the head of bed flat [10]. Instillations into the bladder of larger than standardized volumes may lead to falsely elevated IAP measurements [3]. This procedure is contraindicated or inaccurate in patients with a history of cystectomy, traumatic bladder injury, pelvic packing, or bladder outflow obstruction [6, 8]. Measurements are also affected by variations in intrathoracic pressure associated with the respiratory cycle; thus measurements must be standardly taken at end expiration.

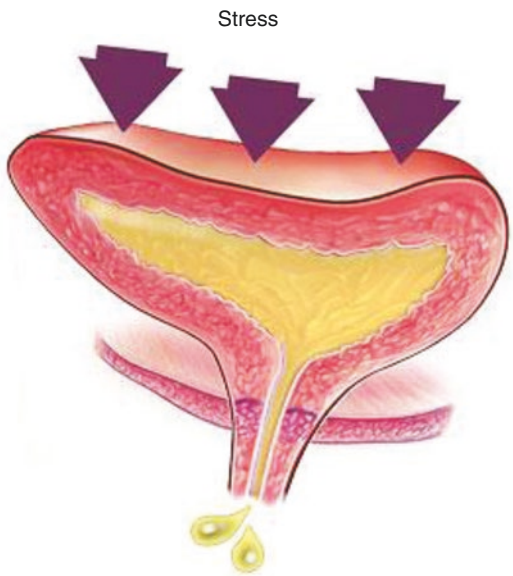

Fig. 31.2 Effects on intra-abdominal pressure on bladder pressure

Alternative methods of measuring IAP include the transduction of inferior vena cava (IVC) through central venous catheter placed through the femoral vein into the IVC [3, 6, 21], intragastric pressure [21, 25], rectal pressure [6, 21], intrauterine pressure [6], and manometry from Jackson-Pratt abdominal drains [3]. Intragastric pressure is obtained with nasogastric or orogastric tube manometry [6, 27]. Although, a viable alternative for patients when a bladder pressure is not possible or misleading the oro- or nasogastric method may be unreliable due to gastric contractions [6, 8]. In the absence of complementary indications such as the need for removal of ascites, direct measurement requiring the placement of intraperitoneal pressure transducers exposes patients to unnecessary risk of complications [6]. Therefore, direct measurement is reserved for those cases where there is pre-existing access in the form of peritoneal dialysis catheter or indwelling ascites drainage catheter [6].

Abdominal perfusion pressure is an analogue to cerebral perfusion pressure [4]. APP is the mean arterial pressure minus the intra-abdominal pressure. APP has been suggested as a more accurate predictor of visceral perfusion and better endpoint of resuscitation than IAP, MAP, lactate, or urine output, although WSACS could make no recommendation regarding use of APP in resuscitation or management of ACS [4, 6]. An APP <60 mmHg predicted the need for surgical decompression [6]. The maintenance of an APP of at least 60 mmHg reduced the incidence of acute renal failure [18, 22].

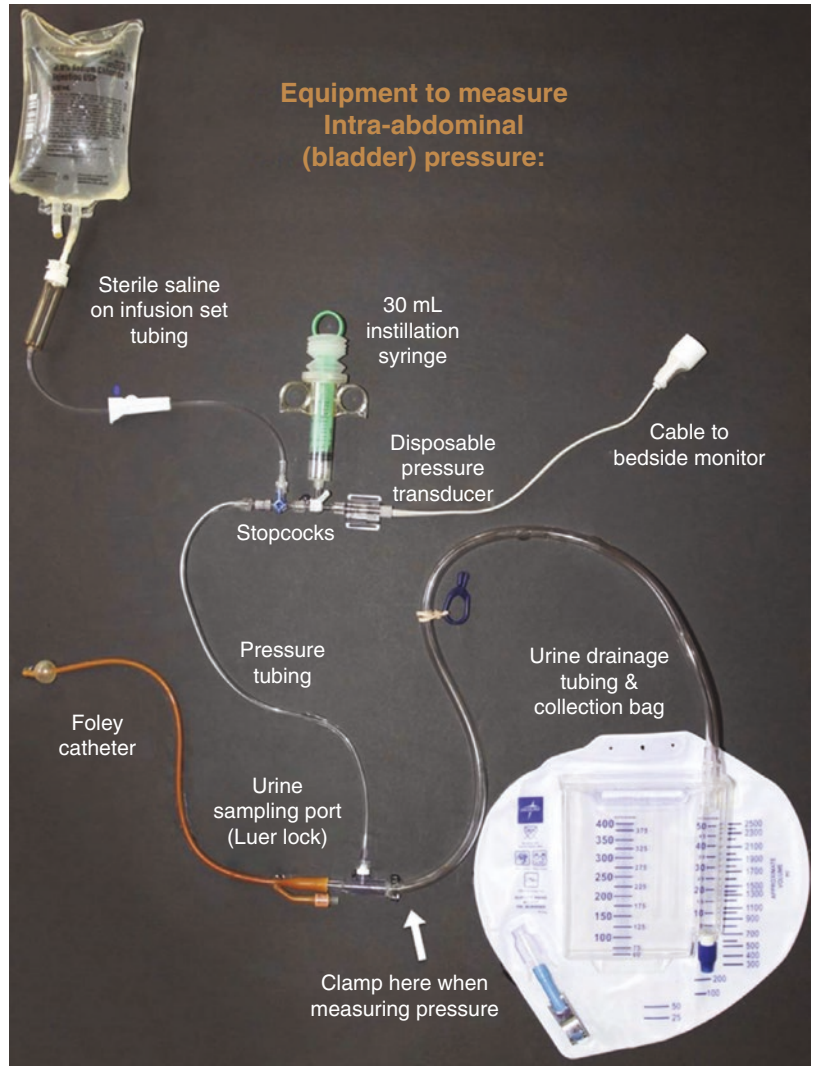

Fig. 31.3 Equipment to measure bladder pressure. (Reprinted from Rogers and Garcia [3]. With permission from Elsevier)

Management

Medical Management

In the management of IAH, the goal IAP should be less than 15 mmHg. This is achieved by tailoring treatment that achieves either reduction of intra-abdominal volume or enhancement of abdominal compartment compliance. Treatment toward these ends is driven by underlying pathology (Fig. 31.4).

Excessive air and fluid within hollow viscera can increase IAP [22]. Evacuation of these intra-luminal contents is achieved directly with nasogastric or rectal tube decompression [10, 11]. Prokinetic agents, such as neostigmine, metoclopramide, and erythromycin, are also useful in the evacuation of intra-luminal contents and decreasing visceral volume [4, 10, 11, 22]. Limiting or discontinuing enteral nutrition will decrease intra-luminal contents [3].

Evacuating intra-abdominal space-occupying lesions will decrease IAP. Often identified with abdominal ultrasound or computed tomography, ascites and blood are the most common components of space-occupying lesions [2, 3]. In the setting of such lesions, paracentesis and large

Table 31.3 Measurement of bladder pressure

Equipment	Sterile saline on infusion tubing 30 mL instillation syringe Disposable pressure transducer Stopcocks Pressure tubing Foley catheter Luer lock Urine drainage tubing & collection bag [3]
Technique	1. Connect components 2. Place patient in supine position. Note that head up position may falsely elevate IAP measurement [3, 22] 3. Flush the tubing to the Foley catheter with sterile saline and zero transducer to atmospheric pressure at iliac crest in midaxillary line [3, 4, 22] 4. Clamp urine drainage tubing immediately distal to pressure sampling line [3]. Instill a maximum 25 mL of sterile saline into the bladder [4]. Volumes of more than 25 mL can overestimate IAP [22] 5. Wait for 30–60 seconds after instillation to allow time for bladder detrusor muscle relaxation. Ensure that stopcocks are off to instillation syringe and IV tubing but open to patient and transducer [3] 6. Pressure should be measured at end expiration in the supine position after ensuring abdominal muscle contractions are absent [1, 3] 7. Remove clamp from urine drainage tubing to drain patient's bladder [3] 8. It is recommended to obtain a baseline IAP measurement when IAH/ACS risk factors are present [22] 9. The measurement of IAP every 4–6 hours should be adequate for critically ill patients deemed at risk for development of IAH or ACS [3, 27]. This monitoring can cease when IAP is less than 12 mmHg for several hours and the patient is clinically improving [3] 10. An alternative means of measurement may be obtained via a standard urinary catheter by introducing a needle into the sampling port and connecting it to a pressure transducer [6]

volume (>1 L) removal of ascites or hematoma significantly decrease IAP [3, 11]. When technically possible, WSACS suggests using percutaneous catheter drainage of ascites, if present, as it may obviate the need for laparotomy [1]. This is most true in patients with secondary ACS due to excessive resuscitation, burns, acute pancreatitis, and primary ascites [22].

Improved abdominal compliance can decrease IAP. Abdominal compliance can be improved by adequate sedation and analgesia reducing muscle tone [3, 10, 11, 22]. Pain, agitation, ventilator dyssynchrony, and use of accessory muscles increase muscle tone and decrease abdominal wall compliance [22]. Neuromuscular blockade can improve IAP by reducing tone in the abdominal musculature [3, 4, 10, 22]. Positioning the patient with the head of bed less than 30 degrees, in reverse Trendelenburg, or supine may aid in decreasing IAP as well [3]. IAP may be decreased by removal of restrictive bandages [3]. Surgical release of restrictive burn eschars or scar tissue will assist in also decreasing IAP [3].

Optimizing the patient's fluid status and avoiding excessive fluid resuscitation will minimize third spacing [3, 10]. An increased or positive fluid balance is associated with third space fluid accumulation and organ dysfunction in animal models [4]. Following resuscitation and hemodynamic capture, diuretics may be used to achieve fluid removal as hemodynamics allow [3, 10]. The combination of diuretic therapy with colloid to mobilize third space edema may be effective [11, 22]. Resuscitation with colloid or hypertonic fluids may also decrease third spacing [3, 6, 22]. One study found using higher amounts of colloid resuscitation had an associated survival in ACS [20]. If renal function is inadequate for diuretic use, the use of renal replacement therapy, hemodialysis, or ultrafiltration may be required for volume removal [3, 10, 11].

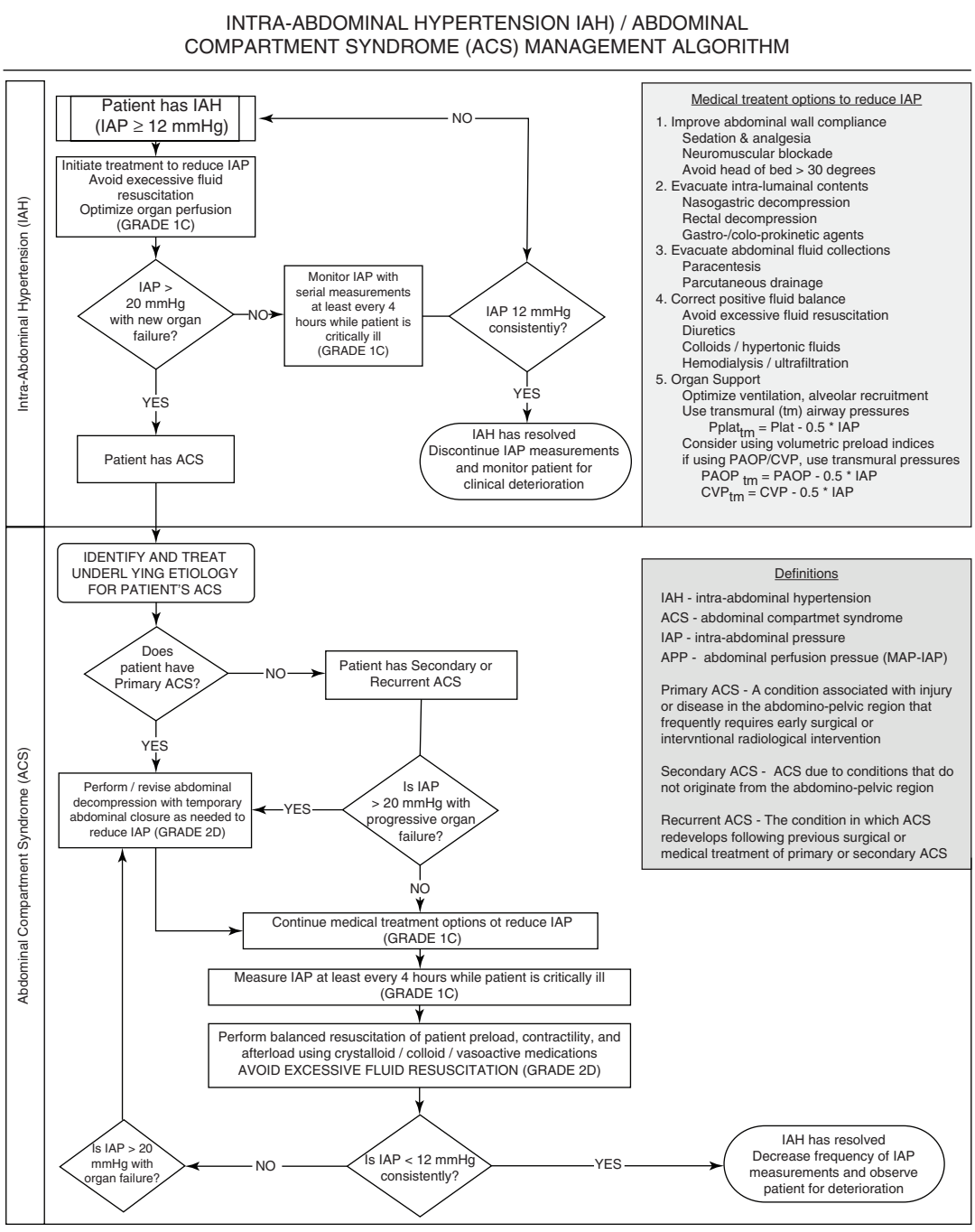

Fig. 31.4 WSACS intra-abdominal hypertension/abdominal compartment syndrome management algorithm. (Reprinted from Kirkpatrick et al. [4]. With permission from Springer Nature)

Ensuring adequate systemic and regional perfusion may minimize end-organ dysfunction. This includes adequate ventilation and alveolar recruitment, goal-directed volume resuscitation [3], and maintenance of an APP greater than 60 with addition of vasopressors if necessary [8]. Although it is not widely accepted, a goal of an APP greater than 60 mmHg has been used as a

resuscitation endpoint that has shown to be more predictive of outcome than IAP [3]. The most important medical therapeutic measures are sedation, zero or negative balance fluid resuscitation, nasogastric and rectal decompression, and neuromuscular blockade [21].

Surgical Management

When nonsurgical management has failed, surgical abdominal decompression and a temporary open abdomen are considered the standard of care [3]. This should be pursued when medical therapies fail or if medical therapies would be inappropriate, such as in the case of hemoperitoneum secondary to abdominal trauma [10]. When done in a timely fashion, surgical decompression reduces mortality by 16–37% [20, 21]. Surgical decompression results in an immediate decrease in IAP to an average of 13.5 mmHg (range of 11–17 mmHg) and improvements in organ function by improving visceral perfusion [3, 4, 19].

An open abdomen is one that requires temporary abdominal closure due to the skin and fascia not being closed after laparotomy [4, 24]. The suggested temporary abdominal closure is a negative pressure wound therapy dressing [21]. When surgical decompression is combined with negative pressure wound therapy, it is proposed to reduce transmission of inflammatory mediators into the bloodstream, with the potential of mollifying septic shock and progressive organ dysfunction [3]. IAP monitoring is necessary even after surgical decompression [3]. The temporary abdominal closure does not prevent the re-development of ACS [1, 26].

An open abdomen should be closed as early as possible with attempts at fascial closure approximately every 48 hours [3]. Early returns to the OR are associated with improved rates of fascial closure and lower rates of infectious complications [5]. Most patients will tolerate primary fascial closure in 5–7 days [22]. Primary fascial closure is generally achieved in 50–60% of patients using vacuum-assisted closure [5]. The patients who remain critically ill past 5–7 days with significant loss of abdominal domain will likely require a skin only closure or split-thickness skin graft [22]. Both of these settings will result in a planned ventral hernia that will need to be repaired in 6–12 months.

Table 31.4 Signs of physiologic exhaustion

Signs of physiologic exhaustion
pH <7.2
Temperature < 34 °C
Estimated blood loss >4 L
Transfusion requirement of >10 units of packed red blood cells
Systolic blood pressure < 70 mmHg
Lactate levels >5 mmol/L
Base deficit > − 6 in patients older than 55 years or > −15 in patients younger than 55 years
International normalized ratio > 1.6

Table 31.5 Management of IAH by grade

IAH grade	Management
I	Sedation, diuresis, paracentesis, and loosening abdominal closure device
II	Sedation, diuresis, paracentesis, and loosening abdominal closure device
III	Neuromuscular blockade, loosening abdominal closure device, and decompressive laparotomy
IV	Decompressive laparotomy

Based on data from Ref. [6]

Prophylactic abdominal decompression should also be considered in patients with expectant IAH/ACS. These patients include those undergoing laparotomy for trauma suffering from physiologic exhaustion (Table 31.4) [4]:

Intraoperative measurement of IAP with fascial edges approximated can be a gauge as to whether closure should be attempted [24]. These strategies have decreased incidence of ACS in trauma patients [3].

Based on the discussion above, Table 31.5 is a summary of management options based on grade of IAH [6].

Complications of Open Abdomen

Inability to achieve primary fascial closure after damage control laparotomy has been associated with increased morbidity and reduced quality of

life among critically ill adults [4]. Potential for morbidity increases commensurate to time with an open abdomen [4]. Complications from an open abdomen include stimulation of hypercatabolic state and protein loss through removal of peritoneal fluid, enterocutaneous and other intestinal fistulas, intra-abdominal infection, retraction of the abdominal wall and development of large ventral hernias, and potential for lethal hemorrhagic complications including exsanguination and reperfusion syndrome [3, 5]. Bacterial colonization of wounds can occur. This risk is greater in patients with synthetic grafts in place [3].

Conflict of Interest No author has a conflict of interest or financial disclosure necessary.

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32 Decompressive Laparotomy

Marialice Gulledge and Cynthia W. Lauer

Introduction

Abdominal compartment syndrome (ACS) and intra-abdominal hypertension (IAH) are terms that present the pathological consequences of "a spectrum of pressures that can affect intra-abdominal tissue viability and organ function" [1]. Interstitial swelling or pressure changes caused by ongoing hemorrhage, hematoma, or ascites can result in a pathological progression of increasing intra-abdominal pressure or IAH. The resulting pressure changes impede kidney and abdominal visceral perfusion and may also impact ventilation and cardiac output [1]. Normal intra-abdominal pressures are described as ranging from 5 to 7 mm Hg in the non-obese individual. Pressures greater than or equal to 12 mm Hg represent IAH, and pressures >20 mm Hg with concomitant new organ dysfunction are defined as ACS. Surgical decompression with midline laparotomy is the standard treatment once ACS with organ dysfunction has occurred [1].

The Operating Room (OR) remains the ideal location for general surgery. In this setting, hygiene, lighting, equipment, staffing, and infrastructure are optimized [2]. However, in patients with an acute intra-abdominal conditions and indications for emergent laparotomy but with concomitant severe cardiopulmonary instability which precludes transport, a bedside resuscitative laparotomy in the Intensive Care Unit may be considered a potential treatment option [3]. In addition, as more complex patients with higher acuities are being transferred to larger academic medical centers there can be difficulty obtaining OR time for non-elective procedures [4]. Bedside laparotomies may allow some simple abdominal procedures to be performed in ICU and avoid the delays and costs of OR time.

Indications

Clinical indications for bedside decompressive laparotomy (DL) include suspected intra-abdominal hypertension/abdominal compartment syndrome. Overall, bedside DL can be considered for those patients who require urgent/emergent intervention or for those with diagnosed or impending ACS. IAH/ACS is seen in a variety of medical and surgical conditions including trauma, sepsis, pancreatitis, massive ascites, retroperitoneal pathologies (ruptured abdominal aortic aneurysm, pelvic fractures with ongoing hemorrhage, etc.), ischemia, burns, and peritonitis [5]. IAH can be further subdivided into grades

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Table 32.1 End-organ effects of IAH

Organ	Associated issues
Brain	Increased jugular vein distention causes impairment of venous return from the brain causing increasing intracranial pressures
Pulmonary	Decreased functional residual capacity with concomitant ventilation/perfusion mismatch impairs oxygenation. Increasing airway pressures can be noted during mechanical ventilation as barotrauma evolves
Cardiac	Cardiac compression from cephalad movement of diaphragm. This results in decreased ventricular compliance and contractility. Increased right ventricular afterload and decreasing cardiac output as venous return is impeded
Skeletal	Decreased preload with vena cava compression. Increased peripheral vascular resistance and femoral venous pressures may reduce arterial flow to the lower extremities
Renal	Renal venous congestion, compression of the renal parenchyma, decreased renal perfusion and activation of renin angiotensin system can lead to injury and oliguria
Abdominal	Increased splanchnic vascular resistance lends to visceral ischemia, bacterial translocation, and lactatemia

Based on data from Ref. [1]

according to the severity, etiology, and rapidity of onset [6]. Abdominal compartment syndrome (ACS) is defined by a sustained IAP > 20 mg Hg pressure which adversely affects circulation and tissue perfusion – ultimately causing organ dysfunction [1]. Increased pressure compromises venous return, cardiac output, and systemic oxygen delivery with confounding effects. As pressure worsens, visceral edema impedes diaphragm movement and ultimately limits alveolar recruitment while elevating pleural and intra peritoneal pressures which further limits venous return and cardiac function [6]. The formation of oxygen free radicals, release of cytokines, and decreased production of adenosine triphosphate may lead to translocation of bacteria and worsening visceral edema further confounding the cycle and predisposing the patient to multiorgan dysfunction [7] (Table 32.1).

Contraindications

Patients with grave underlying conditions such as terminal cancer or severe TBI with suspected herniation, who will not gain any benefit from the risk of decompressive laparotomy, remain an absolute contraindication to the procedure. Another absolute contraindication to bedside decompression would be suspected ruptured abdominal aneurysm, where Operating Room exposure to control active bleeding is mandatory. Relative contraindications to bedside decompression would be significant coagulopathy or suspected severe uncontrolled abdominal hemorrhage, due to the likely need for more exposure and operating room resources for the control of bleeding. Lastly, patients with significant past abdominal surgeries would represent a relative contraindication to bedside laparotomy for decompression given the higher risk of visceral injury and the need for better exposure in OR for any lysis of adhesions needed to adequately decompress.

Risks/Benefits

In critically ill patients with severe or profound metabolic acidosis who require bedside decompressive laparotomy, there is an associated high mortality rate. Additionally, "even when controlling for other known predictors of mortality, IAH is an independent predictor of mortality" [8]. For those patients with intra-abdominal hypertension or abdominal compartment syndrome secondary to resuscitation (e.g., burns, sepsis), and not a primary abdominal process (intraabdominal or retroperitoneal bleeding), consideration may be given to perform an ultrasound of the abdomen in order to determine if a paracentesis or abdominal drain to decompress the ascites would be adequate to avoid

the high risk of decompressive laparotomy. Patients who require decompressive laparotomy are severely ill. However, for those patients with IAH, a decompressive laparotomy can result in significantly lower intra-abdominal pressures and improve hemodynamic and respiratory and renal parameters [9]. Other risk factors for the bedside DL include recurrent hemorrhage, unanticipated need for other specific equipment/instrumentation, crisis management issues (location, spacing, movement of staff in and out of area), device failure, or unanticipated cardiac arrest [4].

As patient's acuity and complexity arise, transportation out of the ICU to the operating room has its own inherent risks including device failure, inadvertent, or unplanned device removal, attendant support or issues, or lack of medications or equipment needed for unplanned events [4]. In such cases, operating in the ICU is a viable and reasonable option, with proper preparation.

Equipment for IAP Monitoring (Fig. 32.1)

- Three way set up
- Pressure cable
- Transducer set
- Urinary catheter
- Urinary collection bag
- Luer lock syringe
- 500 cc sterile 0.9% sodium chloride
- Clamp
- Gloves
- Chlorhexidine or alcohol prep

Additional Equipment Bedside monitor.

Measuring IAP

- Collect supplies
- Place patient in supine position.
- Connect a standard sterile IV saline infusion set to a three-way stop cock with an installation syringe. Attach a disposable pressure transducer.
- Attach pressure tubing to the urine sample port (aka "Luer lock") between a standard Foley catheter and urinary drainage tubing (Fig. 32.2).
- Flush tubing to the Foley catheter with sterile saline and "zero" the transducer to atmospheric pressure at the iliac crest at the mid axillary line (Figs. 32.3 and 32.4).

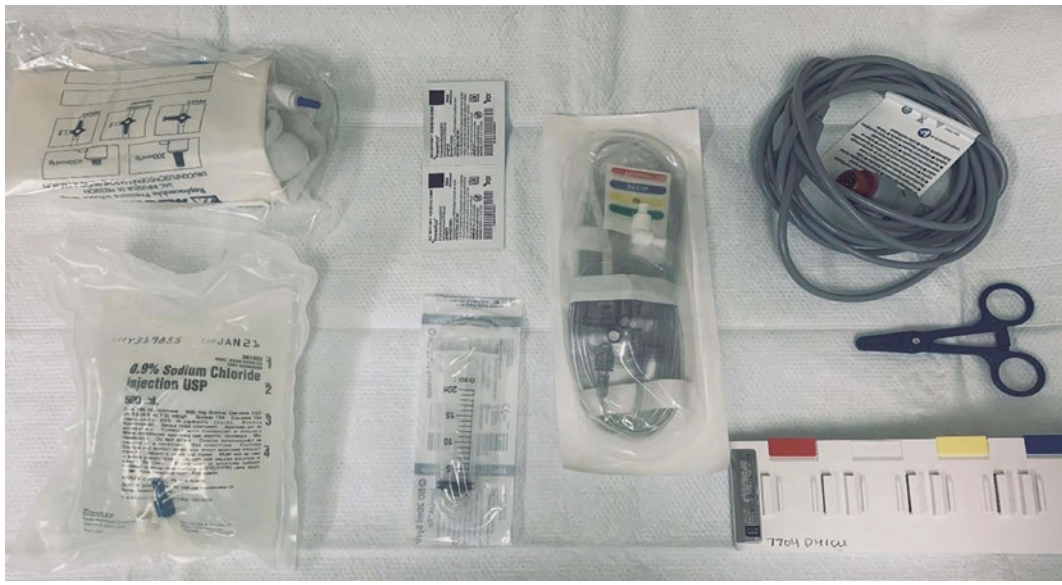

Fig. 32.1 Equipment for IAP monitoring

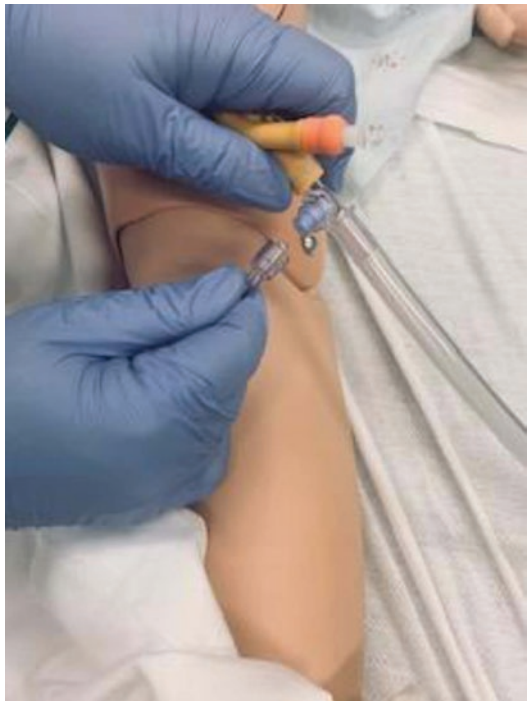

Fig. 32.2 Pressure tubing connected to Foley urine sample port

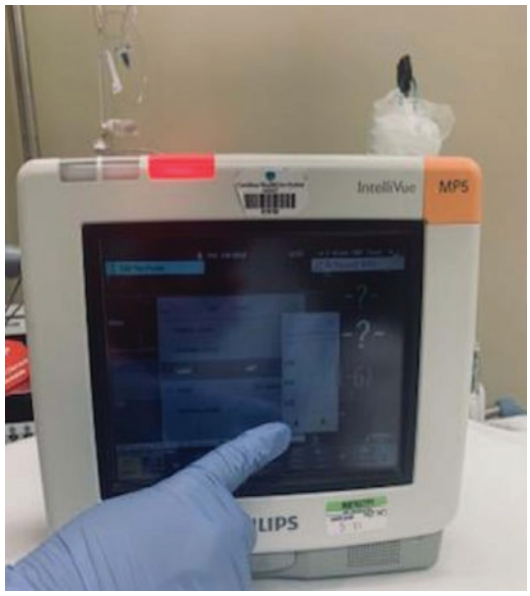

Fig. 32.3 Zero transducer

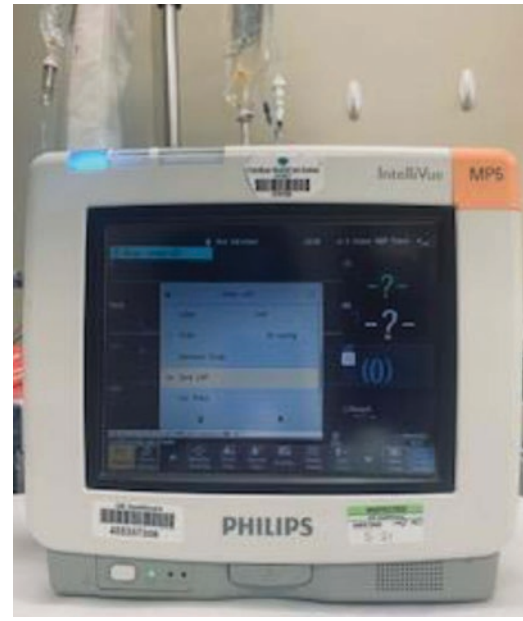

Fig. 32.4 Zero transducer

- Insert ~25 ml or less of sterile saline into the urinary catheter via the closed system and immediately clamp the tubing.
- Wait for ~30–60 seconds after installing to allow for detrusor muscle relaxation and obtain bladder pressure at *end expiration*.
- Reporting of 1 mm Hg = 1.36 cm H20 is recommended for standardization.
- Remove clamp from urine drainage tubing so that bladder can drain.
- Obtain measurements every 4–6 hours as clinically indicated [1].

Preparation for Bedside Laparotomy

- If not emergent procedure, obtain informed consent.
- Key personnel include surgeon, surgical assistant (advance practice provider, resident physician, medical student, registered nurse first assist, etc.), registered nurse, respiratory therapy, and extra runner (for any needed sup-

plies as the bedside RN will not be able to leave).
- Review medical record: current medications, allergies, recent or pertinent laboratory and radiographic studies.
- Optimize ventilator settings – place on mandatory rate with 100% fraction of inspired oxygen (FIO_2).
- Ensure ongoing monitoring of vital signs, cardiac, pulse oximetry, end-tidal carbon dioxide (ETCO2), or other invasive monitoring as indicated.
- Ensure sterile perimeter in room – all individuals in room who are not operating need to be wearing surgical cap, mask, eye protection, gloves, and appropriate personal protective equipment.
- Chlorhexidine gluconate agent of choice for skin preparation.
- Anesthesia: sedation, analgesia, and paralytics if indicated.
- Cross-check equipment function, e.g., suction, electrocautery, etc.
- Prior to starting: Surgeon to and any necessary equipment (e.g. wound vac or improvised vacuum dressing setup) anticipated duration, and contingency plan and perform "time-out."
- Post procedure – collect sharps and instruments.

Equipment List for Bedside Laparotomy

- Electrocautery
- Wall suction
- In-line suction
- Warm balanced crystalloid solution
- Standard bedside laparotomy tray with suture
- Safety towels
- 10/19 French JP drains
- Negative pressure dressings (improvised vacuum dressing if needed, KCI Abthera, etc.)

Procedure for Bedside Laparotomy

The abdomen is prepped widely with chlorhexidine gluconate or betadine and draped with towels. A large drape is applied. The required equipment is assembled and organized on the drape for ease of access. Once the surgeon, RT, bedside nurse, and assistant are ready to proceed, a vertical midline incision is made into the skin sharply and carried down to the fascia with electrocautery. The fascia is opened with extreme caution using cautery or knife, and the abdomen is decompressed. This opening of the fascia is done with great care as the abdominal viscera are under pressure and are at risk for injury during decompression. Usually, for true ACS, this will eviscerate a large volume of fluid, blood, or swollen bowel under pressure (depending on cause for ACS). The fluid is evacuated and the remainder of the fascia is opened from xiphoid to pubis, enabling maximal decompression of the abdomen. Alternatively, if the abdomen was recently closed after a laparotomy and requires reopening, skin staples or wound vac are removed. The fascial sutures are located, cut with a heavy scissors, and removed, opening the entire fascia and allowing evacuation of abdominal contents. This rapid decompression usually results in immediate improvement in venous return and thus improved blood pressure and heart rate. There is the risk of cardiac arrest on opening the abdomen due to profound hemodynamic change. This should be prepared for with code medications and volume loading rapidly available. The abdomen is then inspected for etiology of ACS. Sources such as ascites and hemoperitoneum should have been readily identified on opening. Alternatively, bowel edema, retroperitoneal hemorrhage, and retroperitoneal edema are also possible causes of ACS. The liver is inspected, and the bowel is quickly run from stomach to rectum for obvious ischemia or necrosis. The lesser sac is opened and examined to evaluate for saponification from pancreatitis. Any obvious edema or retroperitoneal hematoma is noted. Any obvious bleeding is controlled and any frankly necrotic bowel is removed. This is beyond the scope of this chapter and may require an operating room, depending on location of ischemia. The abdomen is irrigated copiously and a negative pressure dressing applied. This becomes an open abdomen. Please see chapter on open abdomen and temporary closures.

Complications

Given the physiologic status of the patient, which is frequently nearly moribund, the risk of this procedure is high. The immediate complications include uncontrolled hemorrhage and cardiac arrest from profound hypovolemic shock. If large volume blood loss is anticipated, more consideration for transporting to OR for adequate exposure and lighting is needed. If this is not possible, adequate preparation with blood products, hemostatic agents, suture, and better lighting should strongly be considered. Preparation with crystalloid, blood products, and ACLS drugs should be standard for opening an abdomen in the ICU.

Delayed complications may occur from days to months later. These include possible infectious complications, including intra-abdominal abscess, unrecognized enterotomy, and enterocutaneous fistula. These may be secondary to the underlying insult (i.e., intra-abdominal sepsis) or secondary to iatrogenic injury from the operative technique or the ensuing open abdomen management. Additional iatrogenic injuries to other abdominal viscera are possible but less common. Standard sterile procedure and meticulous technique should minimize these complications as much as possible. Lastly, a common late complication of open abdominal management after decompressive laparotomy for ACS remains a ventral hernia. After decompression, the fascia is sequentially pulled apart from massive edema, and sometimes it is unable to be closed primarily. At this point, the skin may be closed over the open fascia or an absorbable mesh is used to create a temporary barrier between the viscera and the outside environment (and frequently the negative pressure dressing). The mesh is allowed to granulate and eventually a split thickness skin graft is performed for closure of the skin. The patient will have a planned ventral hernia, which may be repaired at a later date after his or her full recovery from his acute illness.

Keys to Success, Perils and Pitfalls

Prevention, prevention, prevention! Luckily, abdominal compartment syndrome has fallen in frequency over recent years. This is largely due to our understanding of the harm of high-volume crystalloid resuscitations. High-volume resuscitations should be avoided in favor of goal-directed therapy and patients receiving high-volume resuscitations should be monitored closely with frequent intra-abdominal bladder pressures (IABP) to identify and follow intra-abdominal hypertension.

Preparation is key! The more prepared you are for this procedure, the easier things will go.

An extra set of hands is crucial for this procedure. While an experienced set of hands is ideal, an inexperienced provider can provide adequate retraction for the surgeon, in order to explore the abdomen, control hemorrhage, and apply a negative pressure dressing.

The surgical supplies of drapes, suction, electrocautery, and a basic laparotomy pan are mandatory. A linear stapler should also be considered if there is concern for bowel ischemia which may require a resection. A skin stapler is very useful for securing all drapes and adjuncts safely on the table. If there is large volume ascites, there may be liters of fluid for evacuation. Therefore, multiple suction canisters are needed on opening the abdomen for ACS.

Resuscitation is ongoing during this procedure, and additional IV crystalloid should be readily available as well as blood products if needed. Code drugs, including epinephrine, calcium, atropine, and bicarbonate are needed to be readily accessible.

CPT Coding

XLAP

XLAP 35840 – Exploration for postoperative hemorrhage, thrombosis or infection; abdomen

XLAP 49002 – Reopening of recent laparotomy

M79.A3. Non traumatic abdominal compartment syndrome

T79.A3XA. Traumatic abdominal compartment syndrome

Summary

Failure to recognize IAH prior to progression of ACS results in hypoperfusion and may ultimately lead to multisystem organ failure and death. ACS can affect the function of nearly every organ system. Bladder pressure monitoring is the standard method to screen for IAH and ACS. Surgical decompression should not be delayed in patients with ACS and may lead to increased mortality [5].

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33 Bedside Laparoscopy in the Intensive Care Unit

Zachary P. Asher and Franklin L. Wright

Introduction

Laparoscopic operations can be both diagnostic and therapeutic in the undifferentiated, unstable, critically ill patient. Effective treatment of sepsis requires not only timely antibiotic therapy and restoration of perfusion but identification and control of the source of infection. While intra-abdominal pathologies are frequent causes of admission to the intensive care unit, critically ill patients can develop intra-abdominal pathologies despite an initially unrelated admitting diagnosis. Diagnoses include, but are not limited to, mesenteric ischemia, intra-abdominal hemorrhage, intestinal volvulus, cholecystitis, colitis, and pancreatitis (Figs. 33.1 and 33.2) [1]. Abdominal sepsis carries high risk of morbidity and mortality even with a definitive diagnosis [2]. The use of vital signs, dosage of vasoactive medications, urine output, lactate clearance, or ventilator requirements are neither sensitive nor specific for intra-abdominal pathology as these can be influenced by a variety of factors. Aside from evaluation for intra-abdominal sepsis, laparoscopy in the hemodynamically stable trauma patient is becoming more widely accepted. Diaphragm injuries, penetrating injuries, or blunt abdominal injuries can be diagnosed and intervened upon using laparoscopy [3].

The physical exam in critically ill patients is limited. Despite advances in minimizing sedative and narcotic administration, many patients are unable to communicate or express pain. Mechanical ventilation and delirium contribute to the inability for the patient to express pain or for providers to elicit pain on physical exam. Pain can also be unreliable or absent in some critical pathologies. Also, ascites, immunosuppression,

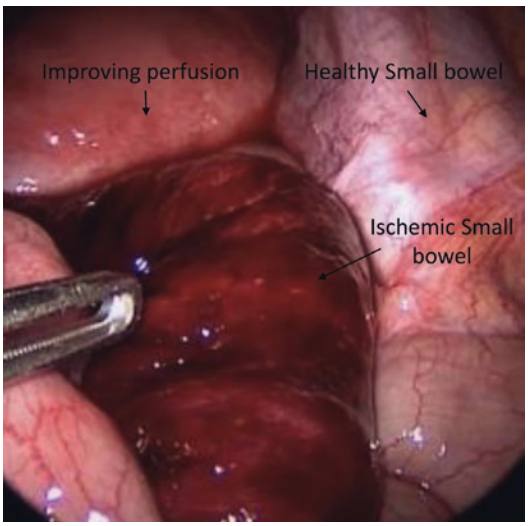

Fig. 33.1 Ischemic, reperfusing, and healthy appearing small bowel

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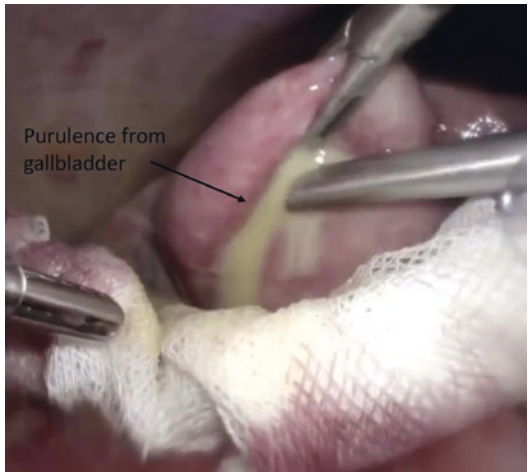

Fig. 33.2 Purulence noted from gallbladder from acute cholecystitis during laparoscopic cholecystectomy

or obesity can limit the abdominal examination. It is challenging to safely obtain adequate radiographic studies on intensive care unit patients. Bedside ultrasound is beneficial due to ease of use and portability; however, dressings, incisions, body habitus, or bowel gas patterns can impair or limit image quality hindering successful diagnosis. In addition, the presence of abdominal fluid in a critically ill patient may be a benign finding in those with cirrhosis or congestive heart failure or may be physiologic from large volume resuscitations. Travelling to radiology suites for either computed tomography or magnetic resonance imagining requires significant burden on staff and can be unsafe based on hemodynamic or ventilatory status. Up to 45% of intensive care unit transports can incur life-threatening complications including line displacement, arrhythmias, hemodynamic instability, and ventilatory instability [1]. A 2009 review found the time to complete a bedside laparoscopy was shorter than the time to complete CT imaging and obtain results [4]. In the situations where physical exam is unreliable, hemodynamic stability is tenuous, or radiologic studies are unsafe or non-diagnostic, bedside laparoscopy in the intensive care unit should be considered, especially in those too unstable to safely leave their room or in whom source control of sepsis is in question.

The first technique involving the use of a scope for diagnosis, cystoscopy, initially utilized candles to examine canine bladders in 1805. This technique was not used in humans until nearly a century later but led to use of scopes for other diagnostic purposes including laparoscopy and thoracoscopy [5]. Despite much controversy and a transient ban in Germany in the late 1950s to early 1960s due to vascular and intestinal injuries during abdominal access, laparoscopic surgery has proven to be a useful tool starting in the early 1980s [5]. Advancements in light sources, access to the peritoneum, electrocautery, and other techniques have made the advancement in minimally invasive surgery possible [6]. Laparoscopy, cystoscopy, and thoracoscopy are now widely used in thoracic, vascular, gynecologic, general, and oncologic surgeries [7]. Laparoscopy is now considered the preferred initial operation for many intra-abdominal pathologies including appendicitis and cholecystitis among other conditions (Figs. 33.3, 33.4, and 33.5). Despite an expansive history with laparoscopy and common utilization in the operating room, the use of laparoscopy in the intensive care unit is relatively new [8].

Bedside laparoscopy in the intensive care unit minimizes the previously mentioned risks relating to obtaining CT or MRI imaging. Transport

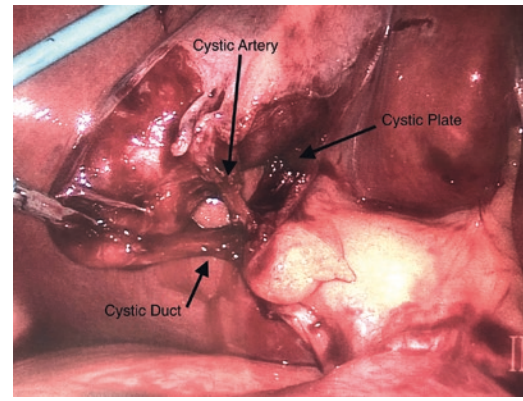

Fig. 33.3 Critical view for laparoscopic cholecystectomy. Gallbladder critical view of safety, two and only two structures seen coursing from the gallbladder toward the porta hepatis. Cystic plate visible and edge of gallbladder visible with no dissection of common bile duct or hepatic arterial structures

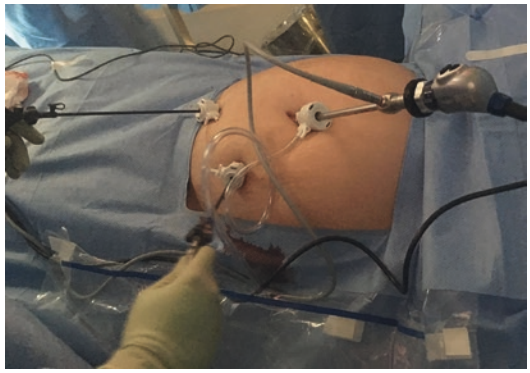

Fig. 33.4 3 port approach for laparoscopic appendectomy

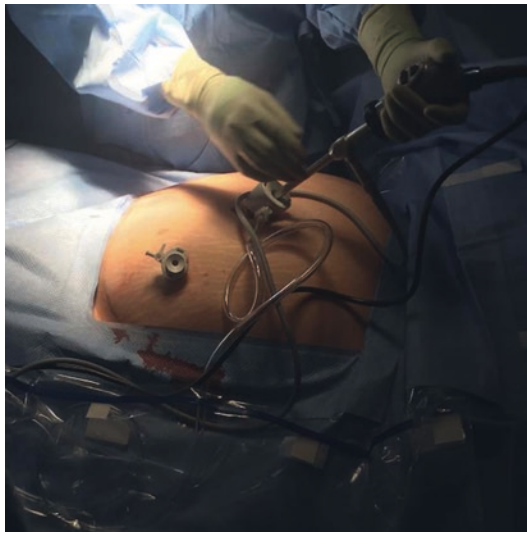

Fig. 33.5 External view of port insertion/preparation

to the operating room may have similar life-threatening complications. The surgical alternative to laparoscopy for the evaluation, diagnosis, and treatment of intra-abdominal emergencies is a laparotomy which harbors significant morbidity and mortality [8]. Damage control or emergent laparotomies have a reported morbidity of 5–22%. Laparoscopy can be a reasonable alternative up to 50% of the time [9]. In a single center study, 18 patients over 16 years with unexplained lactic acidosis had laparoscopies performed with 14 of these patients having positive findings of mesenteric ischemia, gangrenous cholecystitis, hepatic ischemia, acute pancreatitis, gastric volvulus, and uterine pathology with the majority of patients avoiding a laparotomy; unfortunately none of these patients with positive findings survived [10]. Subsequent trials do have more favorable outcomes.

In a retrospective review, over 1/3 of beside laparotomies at a single center were negative, while over 50% of their bedside laparoscopies were positive for intra-abdominal pathologies [11]. They did acknowledge the limited ability to evaluate the retroperitoneum, however advocate for the consideration of a laparoscopic evaluation. Bedside laparoscopy can not only identify and treat possible sources of sepsis but can also exclude intra-abdominal pathologies, encouraging providers to investigate other potential etiologies contributing to the patient's clinical status.

Indications

Critically ill patients without an obvious indication for a laparotomy with unexplained sepsis, lactic acidosis, abdominal pain, or abdominal distension without evidence of an obstruction should be considered for bedside laparoscopy (Fig. 33.6). Additionally, trauma patients with concern for missed diaphragm injury, bowel perforation, or hemorrhage can be evaluated laparoscopically [3]. Diagnostic laparoscopy can avoid an unnecessary laparotomy, expedite a necessary laparotomy based on findings during the laparoscopic operations, or aid in the definitive diagnosis in patients with challenging presentations.

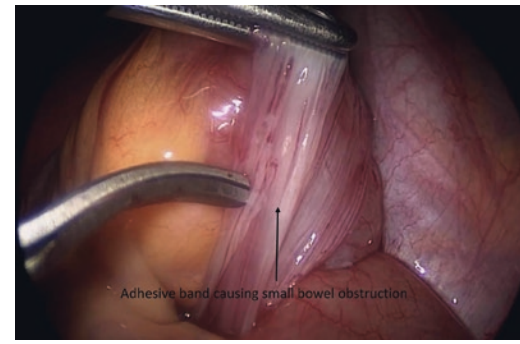

Fig. 33.6 Adhesive band causing small bowel obstruction

Contraindications

The most essential contraindication is those who would not tolerate pneumoperitoneum. This particularly includes those sensitive to changes in carbon dioxide levels, with tenuous volume status, pulmonary hypertension or severe right heart failure, and intolerance to positioning required from optimal laparoscopic views (Trendelenburg or reverse Trendelenburg depending on the location of the intra-abdominal pathology). Patients with uncorrectable coagulopathy, hypercapnia, or dependence on compensatory respiratory alkalosis are not suitable for laparoscopy. Certain intra-abdominal pathologies benefit from a laparotomy instead of laparoscopy and include intra-abdominal hypertension, abdominal compartment syndrome, or feculent peritonitis. Laparotomy within the past 30 days, scars or history of multiple abdominal surgeries, open wounds, or abdominal wall infections should be considered for laparotomy despite the potential benefits of laparoscopy [12].

Risks/Benefits

The majority of complications occur at the time of abdominal access during camera or port access but can also occur from insufflation, dissection, and hemorrhage [13]. The major benefits described above include avoiding transportation complications, faster recovery, and decreased morbidity and mortality compared to an exploratory laparotomy. Smaller incisions, easier pain control, and decreased wound infections or hernia formation contribute to the decreased morbidity associated with laparotomies [7].

Preparation

To elucidate any possible relative or absolute contraindications, a thorough history and exam is essential. History of prior abdominal surgeries including prior hernia repairs, complex abdominal wall closure, or recent abdominal surgeries can make access to the peritoneum nearly impossible and unsafe due to implanted mesh or adhesions. If the patient is unable to provide a clear history, evidence of scars or surgically absent organs on imaging can aid in decision-making. Prior abdominal surgeries, cellulitis, or erythema overlying the desired port placement locations can complicate or preclude a laparoscopic approach. In addition to the surgical history, cardio-pulmonary history is essential due to the physiologic effects of insufflation during laparoscopy [14].

In addition to the history and physical exam, preoperative laboratory studies should be obtained. These include a complete blood count to evaluate for profound anemia or thrombocytopenia, basic metabolic profile, arterial blood gas, coagulation profile including INR, prothrombin time, and thromboelastogram if available or applicable, electrocardiogram, and chest radiograph if time permits. Thorough informed consent including a description of the procedure, benefits, and risks should be obtained by patient or medical decision-maker. Benefits include less pain, quicker time to recovery, and a more accurate or definitive diagnosis or exclusion of a diagnosis; risks include death, need for laparotomy, pain, hemorrhage, infection, and damage to surrounding organs [4].

After proper preoperative evaluation and consent, it is essential to have the appropriate supplies and staff. Depending on institution practices, this typically includes an attending surgeon, anesthesia provider or intensivist team, operating room circulating nurse, scrub tech, and possibly ICU nurse. From an anesthetic standpoint, end tidal CO_2 monitoring should be utilized as insufflation can drastically impact this and critically ill patients may be more sensitive to changes in carbon dioxide.

Necessary equipment includes a mobile laparoscope tower with an image processor, electrocautery, a light source for the camera, and sufficient backup CO_2 tanks for insufflation (Figs. 33.7 and 33.8, Table 33.1). Depending on preference, a monopolar cautery, bipolar vessel sealing system, or harmonic scalpel should be available (Fig. 33.9). An open operative set should be available for any laparoscopic

Fig. 33.7 Storz mobile laparoscope tower

Fig. 33.8 Stryker mobile laparoscope tower

procedure for complications that may arise in addition to lap sponges, a variety of sutures, open suction, retractors, and sufficient lighting for visualization.

Procedure

The patient should be prepped and draped in the usual sterile fashion. Appropriate personal protective equipment and sterile attire should be worn. After an official time out has been performed with all necessary personnel present, the operation can commence. Local anesthetic can be used in conjunction with sedation and analgesia to minimize recall and pain during the operation. The number of instrument ports used and their

Table 33.1 Essential equipment

Mobile laparoscopic tower	Operative materials	Backup equipment
CO_2 insufflator with sufficient backup tanks	Laparoscopic instruments	Open operative set
Light source	Needle drivers	Lap sponges
Electrocautery	Hemostatic agents	Variety of sutures
Monitor X 2	Sutures	Open suction
Image processor	Clip appliers/ staplers	Retractors
	Monopolar vs bipolar vessel sealing system vs harmonic scalpel	Sufficient lighting for open procedure

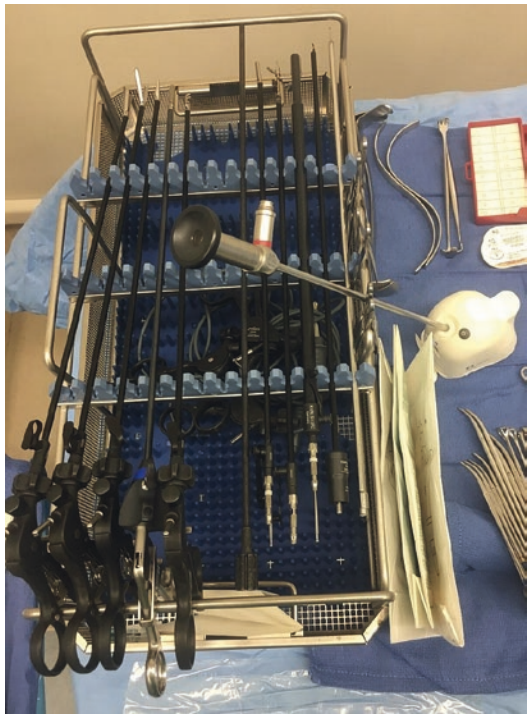

Fig. 33.9 Laparoscopic instrument set

locations in the abdomen depend on the anticipated pathology and surgeon preference. Prior to starting, an orogastric or nasogastric tube and Foley catheter should be placed to decompress the bladder and stomach to avoid inadvertent puncture.

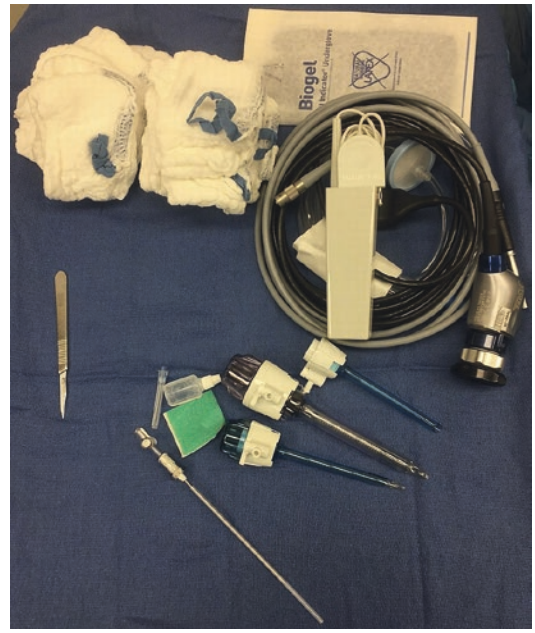

Fig. 33.10 Light source with 10 mm and 5 mm trocars and Veress needle

To establish pneumoperitoneum, a closed Veress needle technique (Figs. 33.10 and 33.11) or an open cutdown technique using a blunt trocar or a Hasson's trocar [15]. In addition, newer optical trocars which allow for direct visualization of the abdominal layers could be used to gain access to the peritoneum. This can be done at the aforementioned periumbilical locations or in the left upper quadrant at Palmer's point. A trocar inserted either infra-, intra-, or supraumbilical location is typically used first after establishing pneumoperitoneum. Once a port is in place, the laparoscope can then help visualize the insertion of subsequent smaller trocars for further access to the abdominal cavity (Fig. 33.12).

The Hasson open technique allows visualization of all of the layers of the abdominal wall during entry but may take longer to start and finish the operation and can present a significant challenge in the obese patient [16]. A scalpel is used to make an incision in the desired location, typically infra- or supraumbilical, followed by blunt dissection of the subcutaneous fat. This can be done with either a tonsil or Kelly clamp. Kocher

Fig. 33.11 Veress needle and laparoscope

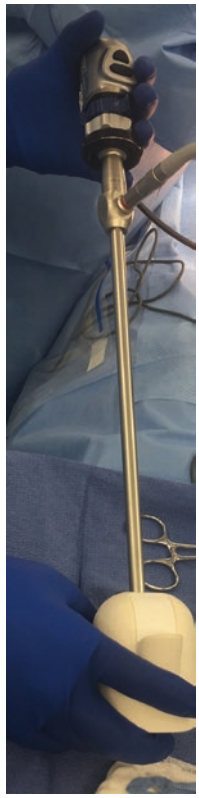

Fig. 33.12 Laparoscope

clamps or a penetrating towel clamp are then placed on the fascia or umbilical stalk followed by incising the fascia and placing stay sutures along the fascial edges [17]. After dissecting the preperitoneal fat, hemostats or forceps are used to bring the peritoneum up which is then sharply opened. Some surgeons use a blunt clamp such as a Kelly to penetrate the peritoneum. A finger sweep of the inside of the abdominal wall is then performed to free the abdominal wall of omentum or bowel. The trocar is then placed through the incision and potentially secured with stay sutures. Some trocars have a balloon in the intraperitoneal portion which can be inflated following insertion to keep the trocar in place and prevent leakage of pneumoperitoneum.

The most common site for the Veress needle to be placed is in the umbilicus given the lack of fat or muscle between the skin and peritoneum. This approach allows quick access to the peritoneal cavity with less chance of subsequent hernias but has increased risk of viscous injury [18]. If the periumbilical location is contraindicated or suboptimal for visualization, Palmer's point, lateral to the rectus muscle in the midclavicular line, 3 cm below the left costal margin can be used to establish pneumoperitoneum [19].

To establish pneumoperitoneum using the Veress needle, after a small incision is made and the appropriate depth is determined, the abdominal wall is elevated with a clamp. The needle is inserted while trying to feel it passing through the fascia and parietal peritoneum. Saline aspiration, hanging drop method, or measuring intraperitoneal pressure can confirm needle placement. There is no evidence to support a preferred method [20]. After placement is confirmed and pneumoperitoneum established, the Veress needle can be removed and the primary port placed.

The camera can then be directed in a methodical manner to evaluate the small bowel, colon, stomach, liver, spleen, gallbladder, and diaphragm. If present, reproductive organs should be evaluated, too. Multiple ports are often needed for thorough evaluation of the abdomen, as bowel graspers are essential for evaluation of the hollow viscera (Figs. 33.13 and 33.14). After the operation is completed, the ports should be removed,

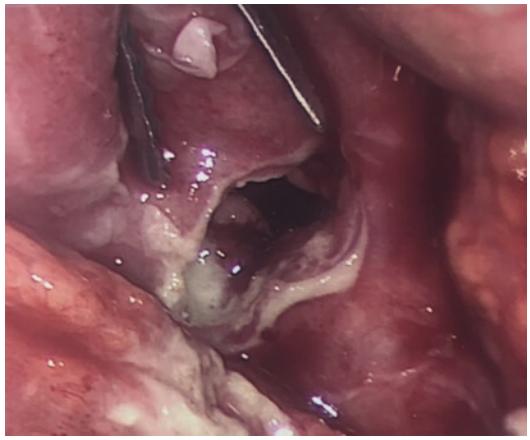

Fig. 33.13 Perforated marginal ulcer after Roux-en-Y gastric bypass operation

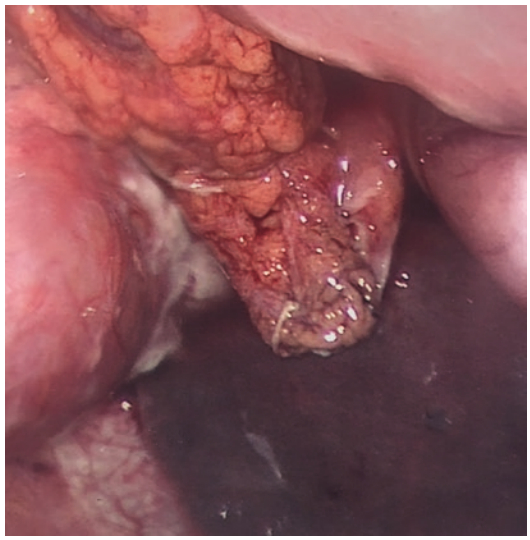

Fig. 33.14 Perforated marginal ulcer status post repair with omental patch

and fascial defects greater than 7–10 mm in size closed as per surgeon preference.

The anesthetic or sedation portion of this procedure may be managed by the intensivist team if appropriately credentialed. Some of the studies mention performing this under local anesthetic with procedural sedation, while others required full general anesthesia [21]. Inhaled anesthetic gases may not be available in the ICU setting requiring total intravenous anesthesia. Proper cardiopulmonary monitoring, arterial and venous access, and airway adjuncts should be evaluated and placed prior to starting the operation.

Complications

Anticipation of the cardiovascular effects of establishing pneumoperitoneum is essential for safe and effective laparoscopic surgery [14]. Patients are frequently placed in Trendelenburg position to optimize visualization, resulting in increasing pressure on the diaphragm which is exacerbated by pneumoperitoneum decreasing venous return. Compression of the inferior vena cava with insufflation further decreases venous return while simultaneously increasing the central venous pressure which can be life threatening with right- or left-sided heart failure [22]. In addition to cardiovascular effects, the use of CO_2 (most commonly used) for insufflation can have respiratory effects, as well, by exacerbating hypercarbia and acidosis [23].

Aside from the cardiovascular complications related to laparoscopic surgery, bleeding, injury to solid or hollow organs, nerve damage, and post-operative hernias can occur. The top three causes of death in the laparoscopic surgery in decreasing order of frequency are anesthesia related, vascular injury, and gastrointestinal injuries [24, 25]. The other complications are less common and carry less morbidity and mortality.

When bleeding is encountered, hemostasis can be achieved via direct pressure or packing, dilute epinephrine, or hemostatic agents. Depending on the source and location of bleeding, sutures, electrocautery, ultrasonic or bipolar tissue sealers, clips, or other surgical devices may aid in hemostasis. If these techniques fail to achieve adequate control, conversion to open should occur. Bowel injuries are frequently less apparent than hemorrhagic complications, and delayed diagnoses have serious ramifications [26].

Summary

Bedside laparoscopy can be utilized as a diagnostic and possibly therapeutic option for the criti-

cally ill patient in the intensive care unit. Identifying and controlling the source of infection or diagnosing a traumatic injury is imperative for survival. Even in patients admitted for etiologies unrelated to intra-abdominal pathology, intra-abdominal pathologies may develop as a consequence of critical illness. Radiologic modalities may be unsafe or inconclusive requiring surgical exploration. Laparoscopy can be considered as an alternative to a laparotomy to decrease morbidity and potentially mortality.

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Additional Resources

https://www.sages.org/video/top-14-part-2-diagnostic-laparoscopy/
https://www.sages.org/video/laparoscopic-cholecystectomy/
https://www.sages.org/video/sages-top-21-videos-laparoscopic-splenectomy/
https://www.sages.org/video/video-symposium-laparoscopic-lysis-of-adhesions/
https://www.sages.org/video/top-14-part-5-laparoscopic-appendectomy/

Diagnostic Peritoneal Lavage

34

Megan H. MacNabb and Melissa Red Hoffman

Introduction

Diagnostic peritoneal lavage (DPL) is a procedure that was first established in the 1960s to diagnose intra-abdominal bleeding after trauma and to help determine the need for subsequent exploratory laparotomy versus nonoperative management when physical exam alone was inadequate [1–3]. Over time, DPL has been validated with excellent sensitivity and reproducibility [4]. However, technological advances in computed tomography (CT) and focused assessment with sonography for trauma (FAST) have limited its use [1, 5].

CT is a noninvasive option that has been shown to be very accurate for the diagnosis of hemoperitoneum and may identify injured organs [1]. On the other hand, it is not necessarily specific for diagnosing blunt bowel or mesenteric injuries and requires interrupting ongoing patient resuscitation [1, 6]. Other factors, like acute kidney injury, can preclude CT as an option; or radiographic interpretation of CT can vary [7]. As a result, CT is typically reserved for hemodynamically stable patients in the form of a secondary trauma survey [1, 5, 6]. This may not be as helpful in a more critical, hemodynamically unstable trauma patient evaluation.

With regard to FAST, the American College of Surgeons has, in recent years, adopted it into the Advanced Trauma Life Support (ATLS) protocol, thereby removing DPL as the first-line diagnostic tool for intra-abdominal hemorrhage [8]. Despite this, there are still reasons that DPL may be a useful and preferred tool in the workup of a trauma patient. While FAST is a noninvasive, less expensive bedside tool that has been both highly sensitive and specific for identifying intra-abdominal injury, its accuracy is operator dependent, and results can be affected by factors like patient body habitus [6]. In comparison, FAST and DPL have been shown to have similar rates of sensitivity and specificity [6, 9]. Additionally, DPL has the advantage over FAST in being able to identify and differentiate between blood and free bowel contents [6].

Consequently, DPL remains a valuable procedure to know; it has comparable sensitivity and specificity rates to determine intra-abdominal injuries [6, 9], and, although invasive, it does not require interrupting resuscitation. Other modalities, namely, CT and FAST, may be more expensive, time-consuming, or unavailable in resource-limited environments [5].

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Indication

Primary Overall Indication

- Hemodynamically *unstable* patients after blunt or penetrating trauma when FAST is not readily available

Blunt trauma is defined as physical injury to a particular anatomical region by way of impact, injury, or physical attack. The most common mechanisms of injury include motor vehicle accidents and falls. Penetrating trauma refers to an injury where an object penetrates the skin and enters the body. Common mechanisms of injury include gunshot and stab wounds [10, 11].

The typical approach, as described in more detail later, is in the infraumbilical location. However, indications for a supraumbilical approach include patients with pelvic fractures, patients with previous lower midline surgeries as evidenced by scarring, and patients who are pregnant [8, 12]. Closed technique is most common, as described below, but indications for open technique include pregnancy, midline scarring, and pelvic fracture (Table 34.1).

Risks/Benefits

The risks of this procedure include complications that are further delineated in section below. Briefly, it is possible to obtain a false-positive result that leads to unnecessary laparotomy. Other major risks include the possibility of hemorrhage or damage as a result of inadvertently contacting a nearby structure as well as infection.

Advantages of DPL include the following:

- Straightforward procedure with readily available equipment (if proceduralist is experienced)
- Low cost
- Quick analysis of results
- Few contraindications

Table 34.1 Contraindications

Absolute contraindications	Relative contraindications
Clear indication for immediate laparotomy	Coagulopathy
	Previous abdominal operations
	Marked obesity
	Advanced pregnancy
	Advanced cirrhosis
	Hemodynamically stable patients
	Access to ultrasound
	Lack of training in DPL procedure

Preparation

Equipment

1. Commercial DPL kit
   - If none available, a typical surgical tray used for laparoscopy with a rigid peritoneal dialysis catheter
2. Foley catheter
3. Nasogastric tube
4. Local anesthetic (1% lidocaine with epinephrine) (Fig. 34.1)

Patient Preparation

Regardless of technique, patients should be prepared in the same manner:

1. Position patient flat in the supine position.
2. Place a nasogastric (NG) tube to decompress the stomach.
3. Place a Foley catheter to decompress the bladder.
4. Surgically prep and drape widely the periumbilical area.
5. Local anesthesia is usually adequate for most patients. IV conscious sedation can be considered in hemodynamically stable patients.
6. For local anesthesia: use 1% lidocaine with epinephrine to decrease the amount of cutaneous bleeding (this could lead to a false positive test).

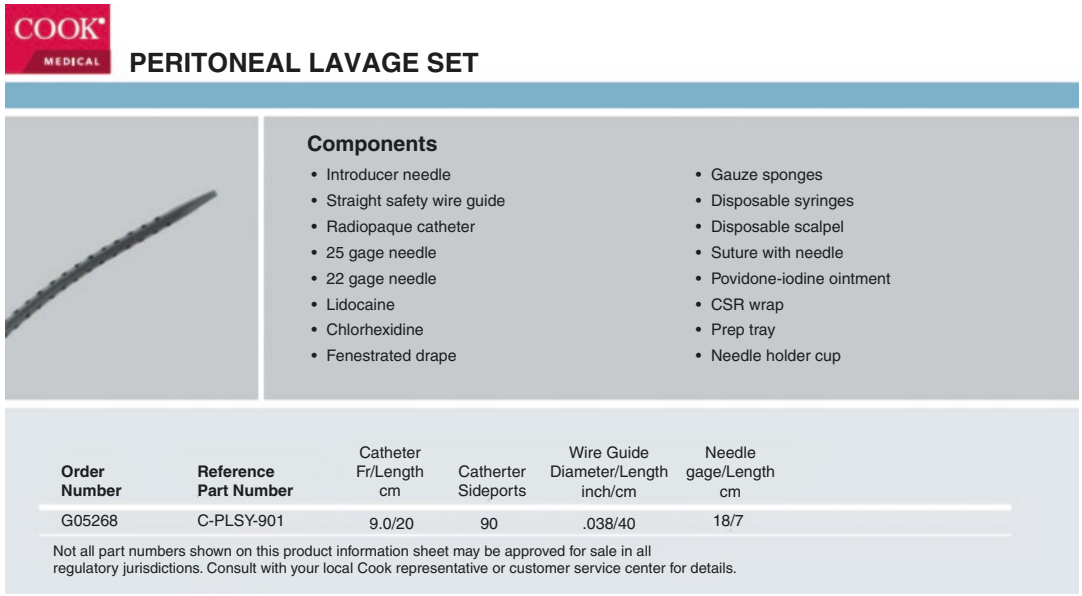

Fig. 34.1 Example of a Commercial DPL Kit. (Permission provided by, Cook Medical, Bloomington, IN https://www.cookmedical.com/data/resources/CC-BM-BSPC-EN-201104.pdf)

Procedure

There are two different approaches to perform DPL: open and closed. The open method uses a vertical infraumbilical incision and direct visualization of the peritoneal entry with a scalpel. The closed approach uses percutaneous needle access to the peritoneal cavity and then Seldinger technique [13].

Studies have shown the closed technique to be simpler, faster, better tolerated, and less expensive without affecting accuracy or complication rate. Open technique, however, might be preferred in situations where closed DPL is relatively contraindicated such as with pregnancy, obesity, coagulopathy, inability to place Foley or NG tube, or prior abdominal surgery [14].

No matter the technique, the procedure consists of two phases. The first phase is deemed the "aspirate" phase because it involves aspirating some fluid from the peritoneal cavity upon entry. The second phase is the "lavage" as it consists of instilling fluid and draining it for further analysis.

Closed Technique

1. Insert the DPL needle and angiocatheter at a 45° angle toward the pelvis.
   - Bifurcation of the aorta lies directly below the umbilicus, so the angle helps avoid inadvertent damage.
2. Resistance will be encountered as the needle traverses the fascia and again as it penetrates the peritoneum.
3. Aspirate continuously as the needle enters the peritoneal cavity.
4. If more than 10 cc of frank blood or bowel contents are aspirated, the procedure is completed.
   - This is a positive DPL and the patient must immediately go for exploratory laparotomy.
5. If 10 cc of frank blood or bowel contents is not aspirated, then remove the syringe and needle leaving the angiocatheter in place.
6. Next, insert the guide wire through the angiocatheter. Always keep a hand on the guidewire.

7. Remove angiocatheter.
8. Use an 11 blade scalpel to make a small 2–3 mm vertical incision just along the guidewire toward the umbilicus. The incision should be through the skin and subcutaneous tissues.
9. Place DPL catheter over guidewire and insert catheter into the abdomen while holding onto the guidewire.
10. Remove guidewire.
11. Connect IV tubing to catheter and instill 900 cc of warm isotonic fluid into the abdominal cavity.

    Notes:
    - If the patient is a pediatric patient, only instill 10 cc/kg of fluid.
    - Do not instill the total volume of the fluid from the bag.
    - Fluids should be isotonic crystalloid and should be warmed to prevent hypothermia.
    - Do not force the fluid in under pressure.
    - Do not introduce air into the system.
12. Once fluid has been instilled into the abdomen, take the fluid bag and place it on the floor or below the level of the patient's abdomen. Gravity allows for fluid to drain back into the bag.
    - Ideally, the entirety of the fluid should return to the bag. At a minimum, 75% of the fluid should come back.
    - You must retrieve a minimum of 600 cc of fluid to make findings valid.

Open (Surgical) Technique

1. Use 11 blade scalpel to make a small 2–3 cm vertical infraumbilical incision. The incision should be through the skin and subcutaneous tissues.
    - Infraumbilical (just below umbilicus) is the preferred type of incision.
    - Supraumbilical (just above umbilicus) can be used if: patient has suspected pelvic fracture, is pregnant, or has a history of lower abdominal surgeries (look for scarring if no history known).
2. Using a hemostat or retractors, spread the subcutaneous fat bluntly until anterior abdominal fascia is visualized.
3. When the fascia is visualized, place two stay 2.0 vicryl sutures on both sides of the incision. Do not tie off. Drape the four ends of the sutures to the side.
4. Next, make a 1–2 cm vertical incision into the fascia between the sutures.
5. The pre-peritoneal fat is spread open with hemostats and the peritoneum is grasped with the hemostats.
6. Grasp the peritoneum a second time and tent it up.
7. Next, make a small 2–3 mm vertical incision in the peritoneum.
8. Insert the catheter inferiorly toward the pelvis.
9. Attach the syringe and aspirate contents.
10. If more than 10 cc of frank blood or bowel contents is aspirated, the procedure will end.
    - This is a positive DPL and the patient must go immediately for exploratory laparotomy.
11. If the aspirate is not positive, connect IV tubing to catheter and instill 900 cc of warm isotonic fluid into abdominal cavity.

    Notes:
    - If the patient is a pediatric patient, only instill 10 cc/kg of fluid.
    - Do not instill the total volume of the fluid from the bag.
    - Fluids should be isotonic crystalloid and should be warmed to prevent hypothermia.
    - Do not force the fluid in under pressure.
    - Do not introduce air into the system.
12. Once fluid has been instilled into the abdomen, take the fluid bag and place it on the floor or below the level of the patient's abdomen. Gravity allows for fluid to drain back into the bag.
    - Ideally, the entirety of the fluid should return to the bag. At minimum, 75% of the fluid should come back.
    - Must retrieve a minimum of 600 cc of fluid to make findings valid.

13. Finally, if the initial findings are inconclusive, then tie together the fascia with your two stay sutures while awaiting analysis.
14. If not sufficiently closed, more sutures may be placed and the skin can be closed with sutures or staples.

After the procedure is completed using either of the above techniques, the interpretation is the key component of diagnosis. Positive findings during a DPL indicate necessary and immediate exploratory laparotomy for the hemodynamically unstable patient. It is important to understand which criteria constitute a positive finding. Positive findings can be separated by the two phases of the procedure. During phase 1 (aspiration), if >10 cc of frank blood or enteric contents is aspirated, the procedure is terminated as the findings are positive and the patient will need to go to the operating room [8]. One study suggested aspiration of at least 10 cc of blood had a positive predictive value of greater than 90% for intraperitoneal injury due to blunt trauma [15] (Table 34.2).

During phase 2, fluid instilled into the abdomen, and then drained, is sent to the lab for biochemical analysis. Controversy has surrounded the interpretation of biochemical analysis findings. The positive criteria for blunt trauma have been mostly agreed upon, but some have argued the criteria for penetrating trauma. Generally, the consensus has been that a positive finding for both blunt and penetrating trauma would be RBC count >100,000 RBC/mm^3.

A white blood cell count (WBC) of >500 WBC/mm^3 can determine bowel injury. Importantly, it is necessary to recognize that the WBC can tend to lag by 3–6 hours [15]. Some studies have also evaluated the efficacy of measuring amylase and alkaline phosphatase levels. One study determined these parameters to be most useful when combined with a positive WBC count [16].

Finally, the volume of lavage returned was directly proportional to the number of RBCs seen. Meaning, the RBC count increased with more fluid recovery. To avoid a false negative, the provider should remove a minimum of 600 cc [15].

Table 34.2 Biochemical analysis: positive findings

Procedure phase		Blunt trauma	Penetrating trauma
Phase 1	Frank blood	10 cc	10 cc
	Frank enteric contents	10 cc	10 cc
Phase 2	RBC count	>100,000 RBC/mm^3	>100,000 RBC/mm^3
	WBC count	>500 WBC/mm^3	>500 WBC/mm^3
	Amylase	>20 IU/L	>20 IU/L
	Alkaline phosphate	>3 IU/L	>3 IU/L
	Enteric contents	+	+

Complications

DPL is an invasive procedure that carries some risk of complication and subsequent injury to the patient. Many studies show a low risk when the provider is experienced with procedures and is familiar with the technique. One study suggested the risk of complication as low as 0.8–2.3% [9]. However, significant experience and judgment is required in patients with prior abdominal surgery, pregnancy, or obesity, where the anatomy makes DPL more technically difficult and there is increased risk of damage to structures underlying the abdominal wall (Table 34.3).

Table 34.3 Possible complications

False positive leading to unnecessary laparotomy
Intra-abdominal or retroperitoneal organ injury
Damage to other surrounding structures
Hemorrhage, especially from damage to the aorta
Bowel perforation
Local wound and/or systemic infection
Site hematoma
Catheter misplacement
Failure to recover warm fluids instilled (which could lead to a false positive finding on a subsequent CT scan)
Scar tissue

Keys to Success

- DPL cannot be performed more than once.
- If DPL is performed prior to CT scan, the CT may have a false-positive read for abdominal abnormality/injury due to instilled fluid leftover from procedure.
- If text can be read through the tubing, it can be considered unofficially negative until the official cell counts return [17].

Troubleshooting

Fluids Remain in the Peritoneal Space

- Make sure the bag is on the floor or at the lowest level below the patient.
- The patient may need to be repositioned (i.e., reverse Trendelenburg).
- Slosh the abdomen to move and shift bowel and fluids.
- Keep some fluid in the bag to allow for a vacuum. If no fluid is left in the bag, fluid will not drain out.

CPT Coding

CPT 49084, Under Incision Procedures on the Abdomen, Peritoneum, and Omentum

CPT 81212, Under Tier 1 Molecular Pathology Procedures [18]

Summary

Historically, physical exam and DPL were the gold standard in identifying trauma patients who needed emergent exploratory laparotomy. However, with technological advances, standard practice via the ATLS guidelines has transitioned to primarily using noninvasive alternatives such as CT scan and FAST. Patients who are hemodynamically stable after blunt or penetrating trauma are usually evaluated with physical examination and CT scan to assess for intra-abdominal injury. Hemodynamically unstable trauma patients can be evaluated using FAST, as it is noninvasive and can usually be performed while resuscitation continues. If the medical provider does not have access to or experience with ultrasound, and has the experience, a DPL can be a useful tool to assess for intra-abdominal injury. Compared with FAST, DPL is similarly quick and accurate in diagnosing hemoperitoneum or hollow viscus injury after trauma.

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Additional Resources

UCSD Trauma, Surgical Procedures Video Library: Diagnostic Peritoneal Lavage. https://www.youtube.com/watch?v=O9BZamRlXVA.

Part VII

Urologic Procedures

Foley Catheterization: Basic to Challenging

35

Jamie W. Vano, Bradley C. Tenny, and Abby Looper

Basic Urethral Anatomy: Male and Female

A basic understanding of the anatomy of the genitourinary system in both males and females is essential in effectively and safely performing urinary tract drainage for all providers.

Male Urethra

On average, the male urethra is 17.5 cm to 20 cm from the bladder neck to the external urethral meatus. The male urethra has several anatomic sections, from distal to proximal: urethral meatus, penile urethra (collective term for the fossa navicularis, pendulous urethra, and bulbous urethra), membranous urethra, prostatic urethra, and the bladder neck. The caliber of the male urethra varies in size dependent upon the anatomic segment. For example, the more proximal portions of the male urethra have a larger caliber (up to 32 Fr), while the more distal segments are narrower (a normal male urethral meatus can accommodate passage of a 24 Fr catheter) [1].

Female Urethra

The female urethra and the bladder neck, found within the anterior portion of the vaginal wall, measures approximately 4 cm. It is also divided into sections, which are known as the distal, mid-urethral, and proximal segments. The average caliber of the female urethra is 22 Fr [1].

Basic Foley Catheter Fundamentals (Preparation and Technique – Up Until Insertion and After Successful Catheter Placement)

When preparing to catheterize a female, begin with the patient in lithotomy position. Males are typically catheterized in the supine position. Handwashing for at least 15 seconds with warm water and soap is essential for sterile procedures and prevention of infection. Supply packages are opened and placed on a sterile field. Rewash hands prior to donning sterile gloves and beginning procedure (Fig. 35.1).

Locate the urethral meatus. Prep the patient with Betadine- or Hibiclens-moistened 4 x 4

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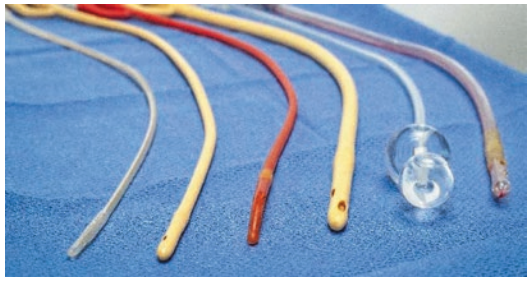

Fig. 35.1 Foley catheters

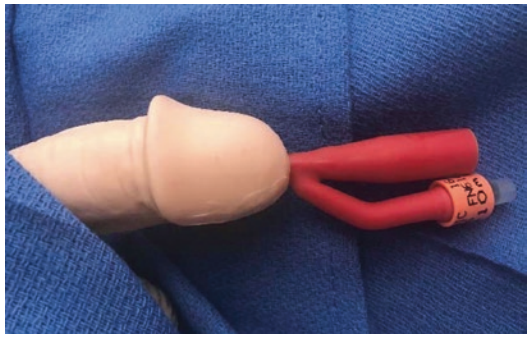

Fig. 35.2 Foley catheter hubbed to Y-junction

gauze starting at the urethral meatus working outward. Drape the patient covering the abdomen, bilateral inguinal regions, and upper thighs. Inject Uro-Jet lidocaine jelly per urethra. It is common for the jelly to run back out of the urethra. Allow the lidocaine to sit for 3–5 minutes for appropriate analgesia.

Insert a well-lubricated catheter into the urethral meatus. Slowly advance the catheter into the bladder until hubbed at the Y-junction (Fig. 35.2).

If there is return of urine, inflate the balloon using a 10 mL syringe with sterile water. If there is not return of urine, check the catheter placement with flush and aspiration of 15 mL normal saline or sterile water using a toomey/piston syringe through the end of the catheter prior to inflating balloon (Fig. 35.3).

Connect the Foley catheter to the drainage collection bag. Secure the tubing of the drainage collection bag to the upper thigh with a leg strap. Place the drainage collection bag below the level of the bladder (Fig. 35.4).

Fig. 35.3 Irrigation to check Foley placement in the bladder

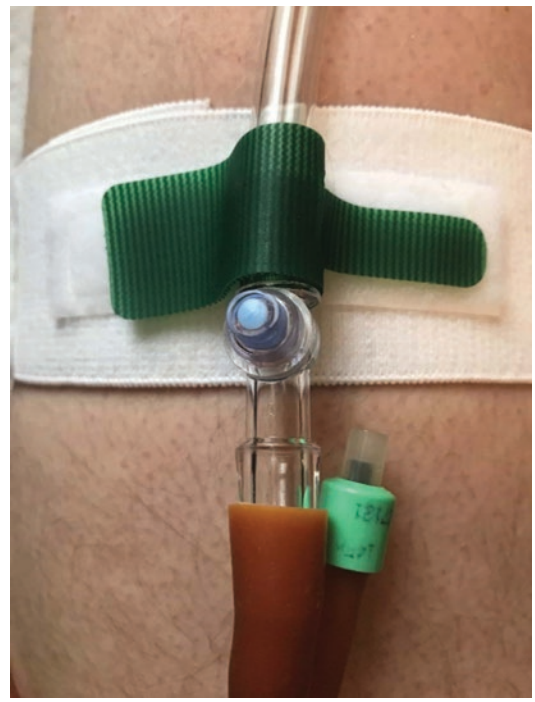

Fig. 35.4 Foley secured with leg strap

Female Urethral Catheterization

Urethral Catheterization for Vaginal Atrophy with Retracted Urethra

Introduction

Vaginal atrophy occurs when there is a lack of estrogen and results in thinning of the vaginal

tissue [2]. This can cause the urethral meatus to be retracted into the vagina making locating the urethral meatus difficult [3].

Indications
Urinary retention, strict monitoring of input and output

Contraindications
None

Risks/Benefits
Risks include multiple insertion attempts, pain during insertion, infection, urethral injury, bladder injury, rectal injury, vaginal injury, and bleeding.

Benefits include bladder rest and precise measurement of urinary output.

Preparation
Supplies needed include 16 or 18 Fr catheter, possibly 12 Fr silicone catheter, Betadine or Hibiclens, 4 × 4 gauze, lubricating jelly, Uro-Jet lidocaine jelly, 10 mL syringe, sterile water, drainage collection bag, leg strap, sterile gloves, and drapes. Explain the procedure to the patient regarding necessity of procedure and expectations.

Procedure
If there is difficulty in locating the urethral meatus due to retraction into the vagina, begin with patient in the Trendelenburg position if able to tolerate [3]. Inserted a well-lubricated, lighted, half speculum into the vagina [3]. Follow basic Foley catheter fundamentals for preparation and securing Foley catheter once successfully placed. Remove the speculum.

Complications
If not located in the urethra, the catheter may curl or advance into the vagina. The location of the Foley catheter can be checked with a toomey syringe and sterile water or normal saline. The amount of solution flushed into the catheter should aspirate with correct placement in the bladder.

Keys to Success, Perils, and Pitfalls
Place the patient in Trendelenburg position for easier visualization of the urethral meatus [3]. A half-lighted speculum inserted into the vagina enables location and visualization of a retracted urethral meatus [3]. A coude catheter can be used with the tip pointed upward to slide along the external genitalia to hook onto and enter the urethral meatus [3]. A lubricated digit can be inserted into the vagina to palpate the location of the urethral meatus and for guidance of a catheter into the urethral meatus. When using a fingertip for guidance, it is often easier to use a 12 Fr silicone catheter because the catheter is stiffer and can be handled easier. Multiple staff members may be needed to hold back the legs and labia to aid in visualization of the urethral meatus for catheterization [3]. It also helps if a staff member holds a pen light to aid in visualization, especially when patients are obese.

Summary
Treatment of vaginal atrophy can be achieved with replacement of estrogen, often used in the form of a vaginal cream. However, vaginal estrogen should be avoided in women with a history of breast cancer, ovarian cancer, or coagulopathy [2].

Male Urethral Catheterization: Buried/Hidden Penis

Difficult Urethral Catheterization for Buried or Hidden Penis

Introduction
Hidden penis occurs when the penis is obscured by a pre-pubic fat pad [2]. This can make it difficult to expose both the urethral meatus and penile shaft making urethral catheterization challenging.

Indications
Urinary retention, strict monitoring of input and output

Contraindications
None

Risks/Benefits

Risks include multiple insertion attempts, pain during insertion, infection, urethral injury, and bleeding.

Benefits include bladder rest and precise measurement of urinary output.

Preparation

Supplies needed include 12 Fr silicone catheter, Betadine or Hibiclens, 4 × 4 gauze, lubricating jelly, Uro-Jet lidocaine jelly, 10 mL syringe, sterile water, drainage collection bag, leg strap, sterile gloves, and drapes. Patient should be in supine position. Explain the procedure to the patient regarding necessity of procedure and expectations.

Procedure

With the patient in supine position, palpate for the penis. With your fingers on the left and right sides of the location of the penis, press down along the sides of the penis [3]. Then, curl your fingertips under the glans penis to expose the urethral meatus. Follow basic Foley catheter fundamentals for preparation. Grasp the penis using the fingertips on either side of the shaft just behind the corona of the glans penis. Stretch the penis outward from the body. Slowly advance the catheter into the bladder until hubbed at the Y-junction. Follow basic Foley catheter fundamentals for securing Foley catheter after successful placement. If the patient is uncircumcised, ensure the foreskin is replaced to prevent paraphimosis.

If there is a large pannus or edema that prevents the exposure of the urethral meatus, an experienced provider may attempt blind passage with a 12 Fr silicone Foley. The patient is prepped with Betadine or Hibiclens. Using a well-lubricated digit, palpate the glans penis to locate the urethral meatus. Using the finger as a guide, slowly pass the Foley catheter into the urethral meatus and advance into the bladder. If unable to determine if the catheter is hubbed, placement will need to be checked with a toomey syringe and sterile water to ensure the balloon is not located in the prostatic urethra.

Complications

If unable to expose the urethral meatus and blind passage was attempted, the catheter may curl if not located in the urethra.

Keys to Success, Perils, and Pitfalls

Exposing the urethral meatus for urethral catheterization often requires an assistant. With a large pannus or edema, it can be difficult to expose the meatus and hold the position during catheterization. One staff member exposes the urethral meatus and holds the position while a second staff member performs urethral catheterization [3].

CPT Coding

Complicated catheterization: 51703

Summary

Long-term management of buried penis includes weight loss, surgical correction, and liposuction [2].

Phimosis

Difficult Foley Insertion Secondary to Phimotic Foreskin

Introduction

Phimosis is the inability to retract the foreskin behind the glans penis. Although this is a normal finding in children <5 years of age, in adults, it may be an acquired condition. Common causes include the buildup of smegma beneath the foreskin secondary to poor hygiene or due to various inflammatory conditions of the glans penis (such as balanitis, a condition common in diabetic patients).

Indications

Urinary retention or other need for catheterization in patients with phimosis or intractable foreskin

Contraindications

Contraindications to catheter insertion, in general, such as after urethral trauma

Risks/Benefits

Inability to retract foreskin or inability to replace foreskin after retraction (paraphimosis), urethral trauma secondary to repeated catheterization attempts, pain during insertion, and infection

Preparation

Gather your supplies, which include catheter of choice (usually 12 Fr silicone catheter or 14–16 Fr coudé catheter), Betadine, 4 × 4 gauze, lubrication jelly +/− lidocaine, 10 mL syringe, sterile water, drainage collection bag, sterile gloves, and drapes.

Place patient in supine position.

Procedure

If possible, the foreskin should be gently moved to allow for the glans and meatus to be visualized. If the meatus still cannot be visualized, catheterization may still be attempted. Follow the standard urethral catheterization preparation as previously described. Obtain your catheter of choice. The ideal catheter for this situation is a 12 Fr silicone catheter. This smaller-caliber catheter allows stiffness and limits coiling so that, as the catheter is inserted beyond the foreskin, the catheter may be guided into the urethra by feel, if unable to be well-visualized. Additionally, a gentle pressure may be applied by the thumb along the dorsal penis and the fingers along the ventral penis to keep the catheter from slipping between the glans and the inner lining of the foreskin. Slowly advance the catheter into the bladder until hubbed at the Y-junction. If there is return of urine, inflate the balloon using 10 mL of sterile water through the balloon port. Connect the distal end of catheter to the drainage collection bag, and secure to the patient or bed. Replace the foreskin if retracted to prevent paraphimosis [4, 5].

Complications

Blind insertion of the catheter from insufficient urethral meatus exposure may result in passage of catheter into the empty space between the glans and the foreskin. Repeated attempts to pass that inadvertently insert into this space may cause trauma, bleeding, and discomfort. Failure to replace retracted foreskin may result in paraphimosis.

CPT Coding

Insertion of temporary indwelling bladder catheter, complicated (altered anatomy): 51703

Summary

Foley catheter placement in men with phimosis can be difficult due to reduced visualization of the urethral meatus. This section describes how to choose the appropriate catheter to navigate this issue and tips on how to advance the catheter without requiring exposure of the urethral meatus.

Hypospadias

Urethral Catheterization for Hypospadias

Introduction

Hypospadias is a congenital displacement of the urethral meatus that results when the urethral folds do not fuse [2]. This can make identification of the true urethral meatus difficult. There may be a cleft in the central glans penis mistaken for the urethral meatus.

Indications

Urinary retention, strict monitoring of input and output

Contraindications

None

Risks/Benefits

Risks include multiple insertion attempts, pain during insertion, infection, urethral injury, and bleeding.

Benefits include bladder rest and precise measurement of urinary output.

Preparation

Supplies needed include 16 or 18 Fr Foley catheter, Betadine or Hibiclens, 4 × 4 gauze, lubricating jelly, Uro-Jet lidocaine jelly, 10 mL syringe, sterile water, drainage collection bag, leg strap, sterile gloves, and drapes. Explain the procedure to the patient regarding necessity of procedure and expectations.

Procedure

Begin by locating the true urethral meatus with the patient in a supine position. Follow basic Foley catheter fundamentals for preparation and securing Foley catheter once successfully placed.

If the patient is uncircumcised, ensure the foreskin is replaced to prevent paraphimosis.

Complications

If the proper location of the urethral meatus is not located, this could result in injury to the penis.

Keys to Success, Perils, and Pitfalls

There is often still a slit in the normal location of the urethral meatus when hypospadias is present. This can result in misidentification of the urethral meatus.

CPT Coding

Complicated catheterization: 51703

Plastic operation of the penis for straightening of chordee (e.g., hypospadias), with or without mobilization of urethra: 54300

Summary

Surgical repair of hypospadias is performed for cosmetic, voiding, sexual activity, and insemination reasons [6]. It is typically performed between the ages of 4 and 6 months but prior to 2 years of age [6].

BPH (Coude)

Difficult Indwelling Urethral Catheterization for Benign Prostatic Hypertrophy (BPH)

Introduction

Benign prostatic hyperplasia (BPH) is a benign enlargement of the prostatic tissue that increases with age [6]. Obstructive voiding symptoms also increase with age and can be monitored with a symptom score, pressure flow testing, and post-void residuals [2]. Due to the anatomy of the urethra in the setting of BPH, it can prove difficult to pass a catheter through the prostatic urethra. A coude catheter may be used to navigate the urethra to enhance catheterization.

Indications

Urinary retention, strict monitoring of input and output, urethral trauma, bladder outlet obstruction (BOO), post-op prostate surgery

Contraindications

Urethral obstructing stone, urethral transection

Risks/Benefits

Risks include multiple insertion attempts, pain during insertion, infection, urethral injury, bladder injury, rectal injury, and bleeding.

Benefits include bladder rest, healing of urethral injury, precise measurement of urinary output, and management of chronic urologic conditions.

Preparation

Supplies needed include 18 Fr coude catheter, Betadine or Hibiclens, 4 × 4 gauze, lubricating jelly, Uro-Jet lidocaine jelly, 10 mL syringe, sterile water, drainage collection bag, leg strap, sterile gloves, and drapes. Patient should be in supine position. Explain the procedure to the patient regarding necessity of procedure and expectations.

Procedure

Begin by exposing the urethral meatus if uncircumcised or hidden/buried penis presents with the patient in a supine position. Follow basic Foley catheter fundamentals for preparation.

With the curved tip pointed upward, insert the coude catheter in the urethral meatus (Fig. 35.5).

Slowly advance the catheter into the bladder until hubbed at the Y-junction [3]. Follow basic Foley catheter fundamentals for securing Foley catheter once successfully placed.

Complications

The catheter may curl at the level of the prostatic urethra. If this occurs, go up a size in the catheter, and re-attempt passage [3]. If the patient has hematuria and the catheter is no longer draining, use a toomey/piston syringe with normal saline or sterile

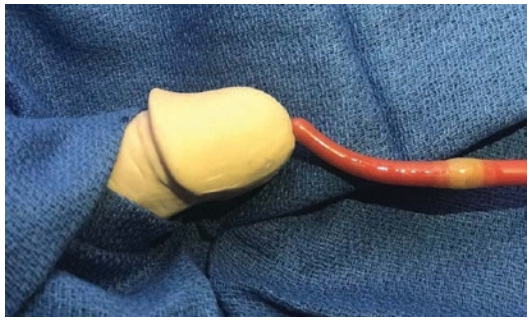

Fig. 35.5 Coude tip pointed upward for insertion

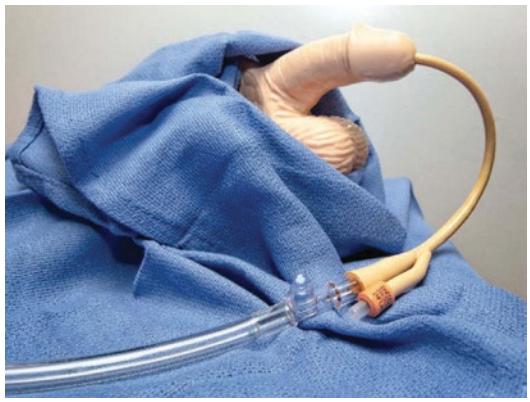

Fig. 35.6 Drainage collection bag tubing with blue sample port

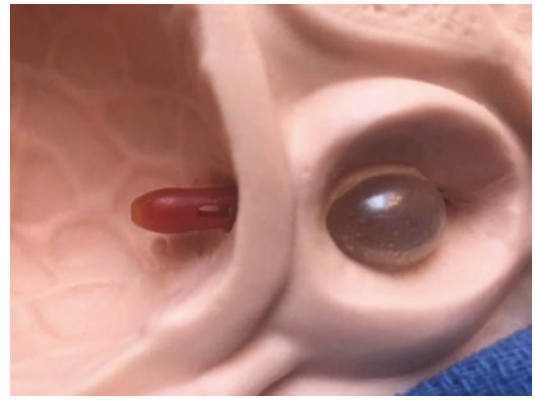

Fig. 35.7 Foley eyelet in bladder with balloon inflated inside the prostate

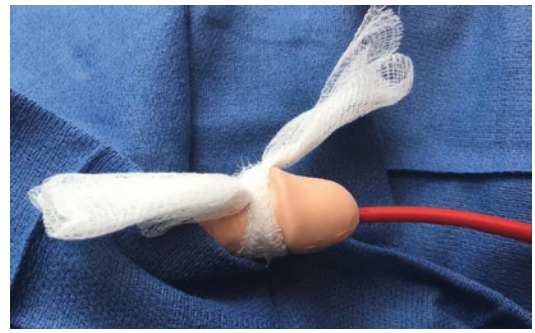

Fig. 35.8 Penile tourniquet

water to perform hand irrigation to clear any clot debris. If a urine sample is required after placement of the catheter, clamp the tubing just below the level of the blue sample port on the drainage collection bag tubing. Wait for urine to build up in the tubing until there is sufficient quantity to obtain at least 3 mL for urine testing. Use an alcohol pad to swab the blue sample port (Fig. 35.6).

Use a 10 mL syringe with blunt needle to aspirate urine specimen from the blue sample port. Then unclamp the drainage collection tubing. The patient should not have pain after placement of the catheter. If there is significant pain, possible inflation of the balloon inside the prostatic urethra should be considered (Fig. 35.7).

This is typically accompanied by bleeding around the catheter or gross hematuria. After adjusting the catheter, a temporary 4 × 4 gauze tourniquet may be applied behind the glans for no more than 5 minutes to staunch bleeding. Leakage of urine around the Foley catheter can result from a blocked catheter or bladder spasms (Fig. 35.8).

Keys to Success, Perils, and Pitfalls

Use a 4 × 4 gauze for more secure hold on the penis during catheter insertion. Getting a good stretch on the penis enables the urethra to stretch out for easier passage of the catheter through the natural curve of the urethra and gentle pressure required for passage through the prostatic urethra. There is a nub on the end of the coude catheter associated with the direction of the curved tip of the catheter to maintain orientation during insertion (Fig. 35.9).

Catheter curling is often encountered with enlarged prostates. Upsizing the catheter gives more stiffness to the catheter so it can pass through the prostatic urethra with gentle pressure [3]. Downsizing the catheter will result in more

Fig. 35.9 Coude nub corresponding to direction of curved tip

curling. Pass the catheter slowly with gentle pressure to avoid urethral injury and the creation of false passages. This also creates less friction to induce less pain for the patient. Having the patient wiggle his toes helps relax the sphincter for easier catheter passage through the prostatic urethra and provides a distraction for the patient. Lidocaine and lubricating jelly can block the eyelet of the catheter causing it not to drain upon placement. Check the placement with a toomey/piston syringe and sterile water or normal saline. The amount of solution flushed into the catheter should aspirate with correct placement in the bladder. This will also clear any jelly or debris blocking the catheter eyelet. Only sterile water should be used for balloon inflation, as normal saline can crystalize the balloon and prevent normal deflation for removal. A leg strap is preferred to a stat lock so the catheter is not pulled on or accidentally placed on tension which can result in bleeding, pain, or traumatic removal. If no Uro-Jet lidocaine jelly is available, the pre-filled syringe of lubricating jelly may be injected into the urethra for lubrication and to open up the urethra [3].

CPT Coding

Insertion of temporary indwelling bladder catheter, complicated (altered anatomy): 51703

Bladder irrigation: 51700

Measurement of post-voiding: 51798

Summary

BPH with bladder outlet obstruction may be treated with catheter drainage, medications, or surgical interventions [6]. Catheter drainage treatments include indwelling urethral Foley catheter, suprapubic tube, or chronic intermittent catheterization. Treatment with medications includes alpha-blockers and 5-alpha-reductase inhibitors [2]. Alpha-blockers relax both the prostate and bladder neck to aid voiding. 5-alpha-reductase inhibitors shrink prostatic size over time. Surgical interventions include both office and operating room procedures. Rezum uses water vapor to destroy prostatic tissue. Transurethral resection of the prostate and GreenLight laser both remove prostatic tissue. Other surgical interventions include prostatectomy, incision of prostate, microwave, and lift procedures.

Additional Resources

O'dea, M. (2017, November 9). *BWU: Coude indwelling catheter insertion educational video* [Video file]. Retrieved from https://www.youtube.com/watch?v=nEdxI_kYVX8

Meatal Stenosis

Difficult Urethral Catheterization for Meatal Stenosis

Introduction

Meatal stenosis is a narrowing of the urethral meatus often resulting from circumcision [6], transurethral manipulation, or lichen sclerosis [2]. This can result in irritative voiding symptoms and make catheterization difficult [7].

Indications

Urinary retention, strict monitoring of input and output

Contraindications

Pinhole opening in the urethra

Risks/Benefits

Risks include multiple insertion attempts, pain during insertion, infection, urethral injury, and bleeding.

Benefits include bladder rest, healing of urethral injury, precise measurement of urinary

output, and management of chronic urologic conditions.

Preparation

Supplies needed include 12 Fr silicone catheter, Van Buren sounds or female dilators, disposable male urethral dilators, hydrophilic glide wire, Betadine or Hibiclens, 4 × 4 gauze, lubricating jelly, Uro-Jet lidocaine jelly, 10 mL syringe, sterile water, drainage collection bag, leg strap, sterile gloves, and drapes. Explain the procedure to the patient regarding necessity of procedure and expectations.

Procedure

Begin by exposing the urethral meatus if uncircumcised or hidden/buried penis presents with the patient in a supine position. Follow basic Foley catheter fundamentals for preparation. Grasp the penis using the fingertips on either side of the shaft just behind the corona of the glans penis (Fig. 35.10).

Using a well-lubricated Van Buren sound, starting with the smallest Fr size, usually 8 Fr, gently insert the sound into the urethral meatus with the tip pointed up. Remove the sound, and repeat the procedure with increasing Fr size as tolerated by the patient [3]. Attempt to dilate to size 16 Fr. Then, attempt to pass a 12 Fr silicone catheter.

If the patient is female, there are female urethral dilators available that are used in the same manner with the curved end pointed upward. Use of a stylet for female patients should only be attempted by a urologic provider with advanced experience.

An alternative is to pass a moistened hydrophilic wire through the meatus into the bladder. Disposable urethral dilators can be passed over the wire to dilate the meatus (Fig. 35.11).

Start with the smallest Fr size dilators, and feed it over the wire. Then, gently insert the dilator into the meatus over the wire (Fig. 35.12).

Withdraw the dilators from the meatus over the wire. Then, increase the Fr size of the dilators as tolerated by the patient to size 16 Fr. Remove the wire, and attempt to pass a 12 Fr silicone Foley. If unable to pass the 12 Fr silicone Foley, replace the hydrophilic wire until coiled in the bladder. Attempt to dilate the meatus to 18 or 20 Fr using dilators. Attempt to pass a 16 Fr council tip Foley catheter over the wire through the urethra until hubbed at the Y junction. If successful, remove the wire prior to inflating the Foley balloon with 10 mL sterile water. Then, follow basic Foley catheter fundamentals for securing Foley catheter once successfully placed.

If the meatus cannot be dilated for passage of urethral catheter, consider placement of a suprapubic tube temporarily.

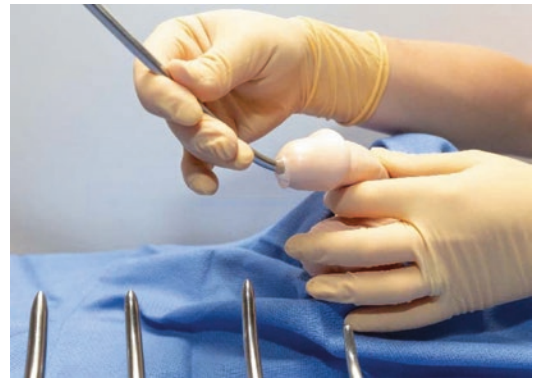

Fig. 35.10 Insertion of Van Buren sound

Fig. 35.11 Disposable Cook urethral dilators

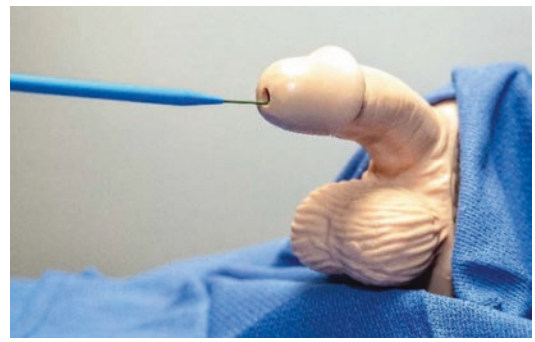

Fig. 35.12 Advancement of disposable Cook dilator over wire

Complications

Urethral injury, infection, bleeding, inability to pass urethral catheter, need for additional procedures, pain, bladder injury, rectal injury, vaginal injury

Keys to Success, Perils, and Pitfalls

The use of a stylet for female patients can result in injury to the urethra, vagina, bladder, or rectum from perforation. This should only be attempted by urologic providers with advanced skills and experience with its use. The use of a hemostat for meatal dilation is not recommended. The use of filiforms and followers is also not recommended, as it is an outdated procedure. A catheter placed after urethral dilation will need to remain in place for a minimum of 5–7 days to prevent quick recurrence of urethral stricture.

CPT Coding

Cystourethroscopy with calibration and/or dilation of urethral stricture or stenosis with or without meatotomy: 52281

Transurethral resection of the prostate: 52601

Contact laser vaporization of prostate: 52648

Meatotomy, cutting of meatus: 53020

Urethromeatoplasty: 53450

Dilation of urethral stricture by passage of sound or urethral dilator, male: 53600

Dilation of female urethra: 53660

Summary

Symptomatic meatal stenosis can be treated with dilation, meatotomy, meatoplasty, or urethroplasty [7].

Male Urethral Stricture/Bladder Neck Contracture

Difficult Urethral Catheterization in Stricture Disease

Introduction

Difficult urethral catheterization of a patient with stricture disease, either scar tissue within the posterior urethra or anterior urethra, requires an astute and knowledgeable clinician. Urethral strictures are primarily a male condition; it is a very rare entity in the female population. Urethral strictures occur primarily in the anterior urethra: the bulbar urethra, pendulous urethra, fossa navicularis, and meatus (meatal stenosis discussed previously as the procedures for instrumentation differ. Example urethral sounds).

Bladder neck contracture differs from urethral stricture disease in that it is primarily an iatrogenic complication from treatment to the prostate. The reported incidence in literature is between 5% and 15% after radical retropubic prostatectomy and approximately 3% after transurethral resection of the prostate [8]. The common occurring theme in these postoperative patients is dense scar formation at or where the prostatic urethra used to be prior to resection.

Either of these two pathologies warrant a urology consultation for Foley catheter insertion if required. Obtaining a thorough medical/urologic history from either the patient, family, or medical chart is imperative prior to performing any procedure. Navigating stricture or bladder neck contracture disease is the skill of the competent urology provider, and there are a few "tools" for the affliction (Fig. 35.13).

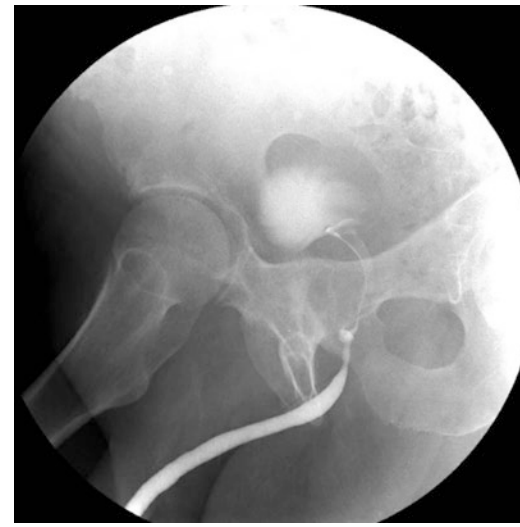

Fig. 35.13 Retrograde urethrogram: radiologist impression is short-segment high-grade stricture at junction of the bulbous and prostatic urethra. No extravasation

Indications

Known history of urethral stricture disease, prior prostatectomy, and prior report of resistance upon initial attempt of catheterization by the nursing staff

Contraindications

If blood drainage is appreciated coming from the meatus, consult urology. There is likely trauma, and the exact problem needs to be determined prior to proceeding with one approach.

For example, with urethral disruption, you should not dilate as the dilation may completely avulse the prior partial tear, worsening the injury.

Risks/Benefits

The patient is treated minimally invasively. The procedure can be performed at the bedside and avoids a trip to the operating room.

Urethral dilation is unfortunately an incomplete intervention that likely warrants more invasive procedures later on, or at least repeat dilation. Even with the minimally invasive surgical approach of DVIU (direct vision internal urethrotomy), the long-term reoccurrence rate approaches 70% [9].

Preparation

Initial setup should be consistent with any attempt at instrumentation of the urethra/bladder.

There are a variety of tools or devices for urethral dilation or navigating around stricture disease. Below are some of the tools that are utilized:

1. Silicone catheters: The alternative to the latex, rubber, or polyvinylchloride (PVC) combination that are typically found within "standard" catheter kits in the hospital [1]. The silicone catheter is the preferred choice for stricture disease; pure silicone catheters are less flimsy allowing for a smoother transition through a scarred urethral lumen if attempted with an appropriate size. Ideally, a 12 Fr silicone catheter should be used with a narrow lumen.
2. Sequential urethral dilators: Dilation of urethral strictures can be performed by a variety of tools; however, today, the more common device is sequential urethral dilators. These dilators typically come with their own guidewire and in a sterilized package (Fig. 35.14).
3. Filiform and followers are not routinely utilized anymore given the assurance of flexible cystoscopy with direct visualization of the wire going into the bladder. Filiform and followers are a "blind" technique at urethral dilation.
4. Council tip catheters: Are any type of catheter that has a hole on the distal end to allow for the advancement over a guidewire.

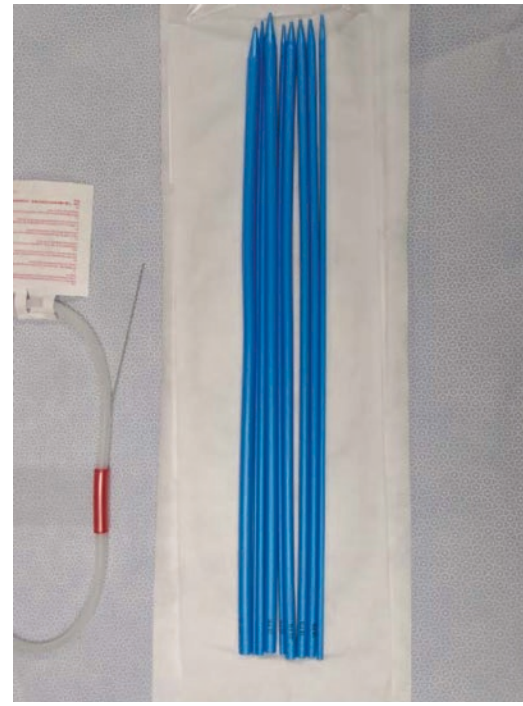

Fig. 35.14 Sequential urethral dilators using the Seldinger technique (over guidewire). This specific pack is from a Cook medical device manufacture

Procedure

Although the American Urologic Association deems blind passage of a guidewire into the urethra an appropriate alternative for flexible cystoscopy if the scope is unattainable, this section will only encompass the steps the experienced urologic provider takes when performing urethral dilation after flexible cystoscopy. Furthermore, the advancement of a 12 Fr silicone catheter is performed under the same technique of passing

any catheter via the urethra and thus has previously been explained.

After flexible cystourethroscopy setup, and advancement of the scope up to the level of the stricture/narrowing, the clinician should follow these steps:

1. Pass guidewire through working/irrigation port. Be sure to pass guidewire while simultaneously visualizing the target of the narrow lumen. We recommend a guide wire with a hydrophilic tip or a complete hydrophilic wire given that these wires are more atraumatic (Fig. 35.15).
2. After successful threading of wire through the stenosed lumen, continue advancing wire to ensure enough of the wire coils in the bladder. This is imperative in order to prevent losing access.
3. Once the wire has coiled within the bladder, push the wire through the scope while simultaneously pulling the scope out of the urethra. The scope should be completely removed while keeping the wire in place.
4. Now that the wire remains in the bladder and the scope is gone, obtain the smallest urethral dilator, and pass it over the wire. Depending upon manufacture, the smallest urethral dilator will either be 5 Fr to 8 Fr. Pass the smallest urethral dilator until a few cm extends out of the urethra (you will use the same technique for passing the urethral dilator as you do when passing a Foley, e.g., penis on stretch, penis pointed up, etc.). When passing the urethral dilator through and beyond the stricture, you should feel steady resistance upon meeting the scar tissue that will eventually give away.
5. With successful passage of the smallest urethral dilator into the bladder, then remove the wire while keeping the dilator in place. This is to observe for a urine drip and confirm correct positioning prior to any further dilation. With urine exiting the urethral dilator, you should then replace the wire through the urethral dilator and into the bladder. Be sure to coil the wire into the bladder in order to prevent losing access. It may be preferable to exchange this wire for a less hydrophilic wire that is less prone to migrating out of the bladder, now that placement has been confirmed.
6. Proceed with sequential urethral dilation using the aforementioned technique of push-pull keeping the wire in place.
7. You may stop urethral dilation with the passage of a urethral dilator that is 2 French sizes greater than the desired Foley catheter.
8. After the urethra has been calibrated to the desired French, obtain a council tip catheter. The council tip catheter should be 2 French sizes below the dilated maximum. Lubricate the catheter and begin passing the catheter over the wire. The same technique of holding the penis and passage of the dilator is used for advancement of the urethral catheter. The wire's primary purpose is to atraumatically guide the catheter through the urethra and into the bladder.
9. The catheter should be hubbed at the meatus prior to removing the wire. Once urine has been returned, inflate the balloon with a sterile 10 cc of water.

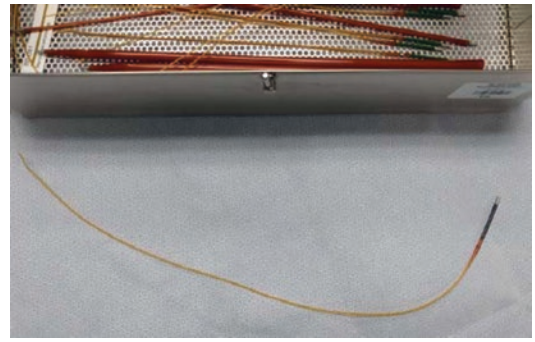

Fig. 35.15 Filiform and followers. The filiform, the flexible guide, is seen outside the sterile pack. These are not disposable instruments

Complications

Any procedure that requires instrumentation of the urethra carries risks of trauma and injury to the said body part. With dilation, there carries a larger risk of perforation, tearing, and avulsion if access into the bladder is not maintained.

Keys to Success, Perils, and Pitfalls

To avoid the biggest pitfall and ensure success, the key is the guide wire. Ensuring that the wire never migrates out of the bladder is imperative for minimally traumatic dilation. To prevent migration of the guide wire, it may be beneficial to have an assistant at bedside or a surgical clamp to secure the wire proximal to the meatus.

If an assistant is present, when advancing the catheter over the wire, have the assistant apply gentle traction on the wire, being careful not to remove the wire, but enough traction to prevent slack in the wire. This will help with passage of the catheter into the urethra.

CPT Coding

51702 – Insertion of a temporary indwelling bladder catheter; simple

51703 – Complicated Foley insertion (altered anatomy, fractured catheter/balloon)

52281– Cystourethroscopy, with calibration and/or dilation of urethral stricture or stenosis, with or without meatotomy, with or without injection procedure for cystography, male or female

53600 – Dilation of urethral stricture by passage of sound or urethral dilator, male

53660 – Dilation of female urethra including suppository and/or instillation

Summary

Urethral stricture disease can be a difficult pathology to circumvent when needing urethral drainage, but with the advent of flexible cystourethroscopy, urethral dilation is an amendable approach for short-term treatment. The urology provider should be consulted whenever this issue is expected in order to ensure correct placement and minimize complications.

Additional Resources

The American Urology Association guidelines provide a surplus of information on urethral stricture disease: https://www.auanet.org/guidelines/urethral-stricture-guideline#x2802

Suprapubic Catheterization

Placement and Exchange of a Suprapubic Catheter

Introduction

Placement of a suprapubic tube/catheter is critical for patients who have had injury to the urethra or those who require chronic urinary drainage with self-catheterization not being feasible. Studies have shown a benefit or decrease in the number of infections and comfort with urinary drainage required >14 days (Fig. 35.16a, b).

Indications

Long-term/chronic urinary drainage, urethral disruption, or any inability to access the bladder via the urethra

Contraindications

Contraindications for SPT placement include previous lower abdominal/suprapubic surgery, current coagulopathy, known history of bladder cancer, and lastly an abdominal wall infection near the planned tract.

Risks/Benefits

Infection and hematuria are the primary injuries that can result from SPT exchange or placement. An exclusive risk to SPT placement is bladder perforation/injury.

A commonly forgotten benefit is the avoidance of urethral structure formation or prevention of urethral erosion from long-standing dependent compression on the ventral urethra.

Preparation

The preparation for SPT exchange is the same for standard urethral insertion. Please follow the guidelines to setting up laid out for you earlier in the chapter.

Preparation for SPT insertion requires:

Patient should be in a supine position or, if possible, a Trendelenburg position. Goal is to limit the amount of bowel that may be overlying

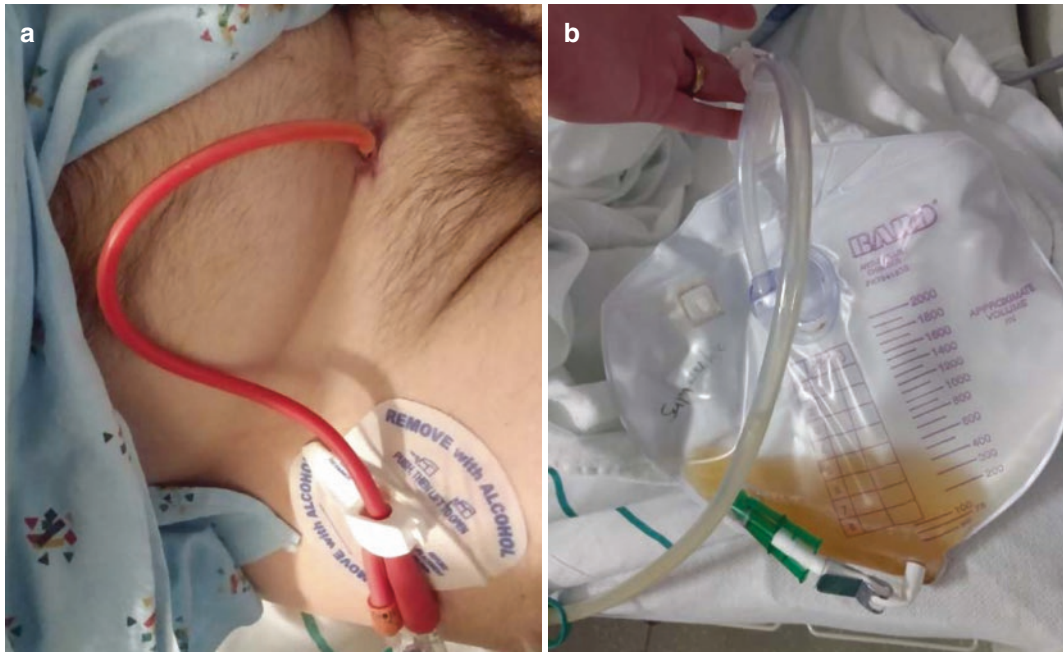

Fig. 35.16 (**a**, **b**) Male patient with indwelling SPT. Urine output amber with minimal sediment

the anterior bladder wall. Obese patients with a panniculus will require either an assistant or tape to retract the overlying fat tissue from the desired insertion site.

The bladder should be distended! The minimum volume that should be in the bladder prior to percutaneous tract formation should be 300 cc [10].

Local anesthetic is recommended for the alert and oriented patient. If desired, a longer-acting anesthetic, with a half-life >24 hrs, can be used for the obtunded patient with expected acute return to baseline (Fig. 35.17).

Kits for suprapubic catheterization should be readily available within the hospital. The variety in kits can range from a trocar-based approach (the kit which comes with a peel-away trocar for advancement of the catheter through) to a Seldinger approach that involves access over a wire with subsequent dilation.

Procedure

Given that an interventional radiology or a urology provider should perform an initial suprapubic tube insertion, discussions for procedural steps for SPT insertion go beyond the scope of this book. Recommend IR or urology consultation for emergent placement.

Exchange of SPT:

Exchange of a suprapubic catheter should only be done if the tract has been allowed to mature over approx. 4 weeks. In our department, we typically recommend 6 weeks prior to the first exchange.

The process of exchanging a suprapubic catheter is more straightforward than exchanging a urethral Foley catheter.

1. Follow the standard prep and drape steps taken with Foley catheter insertion, and apply these to the suprapubic catheter site. Be sure to prep the older suprapubic catheter in while prepping around the suprapubic tract.
2. Deflate the balloon, ensuring that all the sterile water has been emptied. The port should collapse once completely evacuated. If unable to pull back any fluid, cut the balloon port off, and observe for the sterile water to drain out. If no fluid comes out after cutting of the port, proceed with the same steps taken mentioned in the difficult Foley insertion with regard to troubleshooting the balloon port.

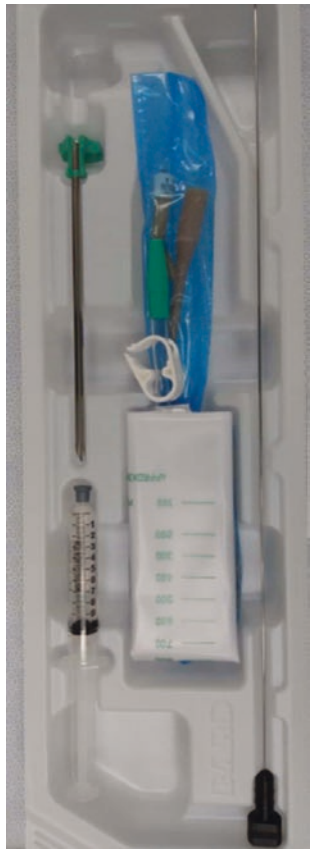

Fig. 35.17 Sterile disposable kit for suprapubic catheter insertion. Picture above is the Bard SPT insertion kit; the trochar is seen in the top left with the blade pointing down

3. With your non-dominant hand, grasp the old deflated catheter, and with your dominant hand, grasp the new lubricated catheter.
4. Slowly withdraw the old catheter, and once extubated, insert the new lubricated catheter until urine is returned then 2–4 cm further.
5. While keeping the new catheter in the bladder, inflate the balloon using 10 cc of sterile water. Note that there should be absolutely no resistance with inflating the balloon.
6. Retract the balloon to seat it at the intraluminal entrance of the suprapubic tract.
7. Then hook to drainage.
   (a) Expert move: Instilling 60 cc of sterile water into the older catheter prior to replacement of the new will allow for assurance of correct placement.

Complications

Complications from the presence of a Foley catheter are relatively consistent despite being in the urethra or a surgically created tract. These complications consist of urinary tract infection, hematuria, catheter blockage/occlusion, and/or traumatic removal.

SPT placement comes with newer risks and complications, as previously discussed, that include bowel perforation.

CPT Coding

Insertion of temporary indwelling bladder catheter, complicated (altered anatomy): 51703

Summary

Foley catheter placement in men with phimosis can be difficult due to reduced visualization of the urethral meatus. This section describes how to choose the appropriate catheter to navigate this issue and tips on how to advance the catheter without requiring exposure of the urethral meatus.

Troubleshooting Common Catheter Problems

Leaking Around the Catheter

Leaking around a suprapubic catheter or urethral Foley can be due to a few causes. The nidus can be due to bladder spasms, a clogged/occluded Foley catheter, or both. Bladder spasms can and do occur in patients who have more "sensitive"/irritable bladders because the bladder is not able to differentiate between what is a foreign body or urine. Bladder spasms can additionally occur if there is straining with a bowel movement, as the pelvic plexus will additionally stimulate the detrusor muscle of the bladder causing volitional voiding. This of course only occurs in patients who have a competent neurologic system.

When catheters get clogged or occluded, urine will leak out around the catheter via the urethra or the SPT tract as this new tract is now the path of least resistance. In suprapubic catheter patients, the SPT tract is without a sphincter that

keeps urine inside the bladder. When a catheter is occluded, the bladder will distend and as a result will leak out around the SPT.

When a urethral Foley catheter is occluded, the bladder will distend; however, the internal and external sphincter of the urethra prevent urine leaking around the Foley. If the distention increases to a point where the intravesical pressure exceeds the static resting pressure of the urethral sphincter tone or increases to the point to cause reflexive contraction of the detrusor muscle of the bladder, the end result with be a voiding of urine around the Foley.

Catheter occlusion without hematuria is likely secondary to encrustation, rather than an intermittent clot occupying the catheter's internal lumen. Encrustation primarily develops in the setting of urinary tract infection, specifically infection from urease-producing organisms such as proteus mirabilis [11]. Intravesical urease will generate ammonia from urea that is filtered from the kidneys resulting in alkaline urine. Over time, the alkaline pH causes precipitation of calcium and magnesium phosphate crystals that preferentially adhere to a foreign body [12].

Methods in preventing catheter occlusion include maintaining routine catheter exchanges, keeping the patient well hydrated, teaching the patient or his/her caregiver how to irrigate the catheter, medications that treat urinary tract infections or acidify the urine, and lastly possibly surgery if a dense stone has formed on the tip of catheter preventing removal/exchange.

Methods in preventing bladder spasms encompass pharmacologic agents. Anti-muscarinic agents work to relax the parasympathetic input that induces bladder contraction.

No Return of Urine After Foley Insertion

When urine does not come out at the end of the catheter to confirm correct position, it can be due a few problems. The first and more worrisome issue is when the catheter is not in the bladder and is in fact in a false passage or coiled within the prostate. Using the appropriate Foley catheter, such as a coude tip catheter for patients with BPH or a smaller silicone catheter with a history of stricture disease, will hopefully reduce the risk of incorrect insertion and the likelihood of urethral trauma. If the correct type of catheter was not initially utilized on the initial attempt, a repeat attempt with correct type of catheter should be attempted prior to consulting the urology service for assistance.

The most common causes of a lack of urine return post insertion are the following:

- An already decompressed bladder and the clinician is performing an exchange. In this setting, it is best to pre-fill the bladder with sterile solution, preferably saline, prior to Foley removal. This will allow for confirmation of being within the bladder upon insertion.
- Too much lubrication was used. When performing Foley insertion, the forward-thinking clinician may use a liberal amount of lubrication on the Foley catheter and may even instill lubrication directly into the urethra (expert move!) prior to insertion to ensure that the urethra is already open for the Foley to "slide right on through" to the bladder. In this scenario, we recommend that the clinician confirm placement by injecting sterile saline through the main lumen of the Foley catheter to remove the lubrication from the catheter eyelets. Injection with a 10 cc sterile saline flush directly through the catheter lumen should be sufficient in this situation, because we are only attempting to relieve obstruction from lubrication jelly and are not trying to evacuate a blood clot.

If all these situations have been ruled out and there is still no urine return, it is best to contact urology and abort catheterization attempt. Inappropriate filling of the Foley balloon within the urethra is a traumatic injury that can result in significant hematuria, possible stricture disease, and increased hospital costs due to requirement for further treatment, the most important concept with Foley insertion.

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Suggested Reading

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Catheterization of Atypical Urinary Reservoirs and Clot Evacuation

36

Jaclyn M. Mieczkowski and Bradley C. Tenny

Perineal Urethrostomy

Introduction

Perineal urethrostomy is a salvage option for patients with complex urethral conditions such as extensive stricture or refractory urethral stricture disease but may be also used as a urinary diversion for oncologic patients after penectomy or urethrectomy for malignancy. A perineal urethrostomy is created making an outlet proximally to the bulbar urethra, distal to the external sphincter. This allows for urinary continence and diverts urine. The entrance of this urinary diversion would be visualized on a male at the base of the scrotum or perineal area [1].

Indications

Bladder catheterization may be needed for acute urinary retention, collection of a sterile urine specimen, monitoring of urine output, patient comfort in the terminally ill, and skin breakdown associated with urinary incontinence [2].

Contraindications

Relative contraindications may include acute prostatitis or an uncooperative patient and a suspected urethral disruption or extensive pelvic trauma [2].

Risks/Benefits

Risks would include infection, pain, urethral injury, gross hematuria, and urinary urgency and frequency.

Benefits could include resolution of urinary retention, resolution of discomfort, improved renal function, and improved monitoring of urinary output.

Preparation

Equipment

- Foley catheter 16 or 18 French silicone or silicone coated
- Water-soluble lubricant or 2% lidocaine jelly with applicator
- Sterile towels
- Sterile gloves
- Betadine and cotton swabs
- 10 cc syringe with sterile water
- Urinary drainage bag

Procedure

1. Obtain consent from patient. Discuss the risks and benefits of the procedure. Ensure all questions are answered.
2. Use universal precautions for protection against blood and body fluids.

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3. Place the patient in a supine lithotomy position.
4. Prep and drape perineal area with Betadine.
5. If using, apply 2% lidocaine jelly into urethral opening using applicator, and leave in place for 5–10 minutes.
6. With the non-dominant hand, apply traction up on scrotum for visualization of perineal urethrostomy.
7. Using the dominant hand, insert the full length of the Foley catheter into the bladder until the junction of the balloon port.
8. Inflate the balloon port with 10 cc of sterile water.
9. Apply gentle tension and pull catheter down until the balloon is against the bladder neck [2].

Complications

1. Hematuria
2. Urethral stricture
3. Urinary tract infection, pyelonephritis, urosepsis, or epididymitis
4. False passage creation or perforation [2]

Keys to Success, Perils, and Pitfalls

1. If urine does not flow freely after catheter placement, consider using a toomey syringe and 30–60 cc of normal saline to flush the catheter and ensure placement and patency of catheter. Lubricant jelly can clog the outlet of urine.
2. Once in place, secure the catheter to the patient with a leg strap to prevent additional trauma if catheter is tugged.
3. If catheter is not easily passed, request urology consultation [2].

CPT Coding

- 51701 Placement of a non-dwelling catheter into the bladder
- 51702 Simple placement of a bladder catheter
- 51703 Complex placement of a bladder catheter

Summary

Providers may encounter perineal urethrostomies on patients with history of urethral stricture of urologic malignancy requiring penectomy or urethrectomy. Patient catheterization should be considered on patients if indicated and should be approached using sterile technique as noted above.

Ileal Conduit

Catheterization of Ileal Conduit and Obtaining a Urine Culture (Figs. 36.1 and 36.2)

Introduction

The most common urinary diversion, ureteroileal diversion, is created using an 18–20 cm segment of the ileum. The conduit is typically positioned in the right lower quadrant of the abdomen. The ureters are re-implanted into the conduit individually with single J 7 to 8F ureteral stents placed through the ureteral anastomosis and out the conduit into a urinary drainage bag to facilitate anastomotic healing. The stents will usually remain in place until postoperative day 5 [3].

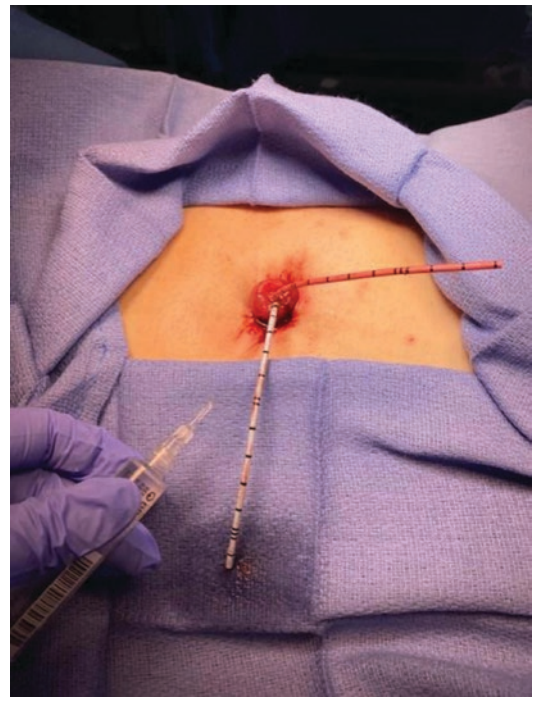

Fig. 36.1 Needless syringe tip with ileal conduit ureteral stents

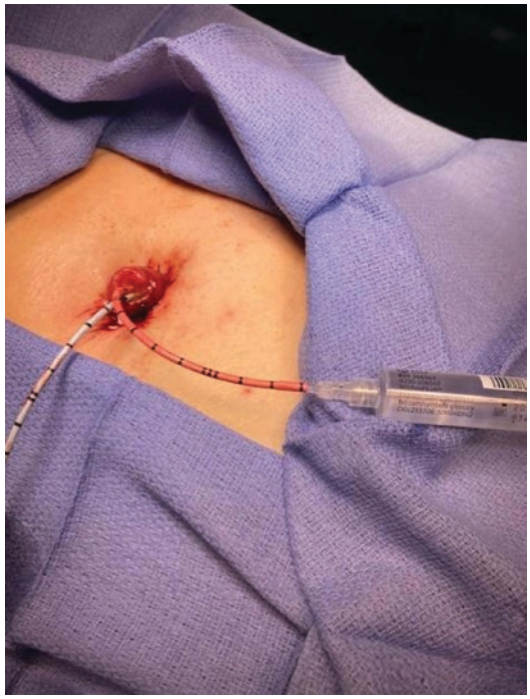

Fig. 36.2 Ileal conduit with ureteral stents. Demonstration of flushing/aspirating stent

External stoma complication rates can range between 15 and 65%. Over time, the risk of stomal stenosis increases. This can lead to urinary retention and upper tract obstruction. This is typically evaluated and managed with catheterization and measuring of residual urine [3].

Indications

- Fascial stricture with retention
- Urine culture

Contraindications

Relative contraindications could include an uncooperative patient. Note: Do not force the catheter into the stoma if significant resistance is encountered [4]. Consider a urology consult if unable to easily pass a catheter.

Risks/Benefits

Risks of this procedure may include bleeding, infection, or damage to the ileal conduit.

Benefits may include obtaining accurate urine specimen, clearance of ureteral stent blockage, management of stomal stenosis with preservation of pouch and reducing risk of rupture, and improvement in urine output and renal function.

Preparation

Supplies

- Cleansing solution
- Gauze
- 16 French catheter
- Lubrication gel
- Sterile specimen container
- Sterile gloves
- Replacement pouching system
- Wash cloths for cleaning and replacing pouch

If placing catheter for stomal stenosis:

- Silk suture
- Suture kit with needle diver, forceps, and suture scissor

If aspirating or irrigating ureteral stents:

- Scissors
- Needleless med prep cannula
- 10 cc syringe
- 10 cc sterile saline

Procedure

1. Obtain consent from the patient. Discuss the risks and benefits of the procedure. Ensure all questions are answered.
2. Use universal precautions for protection against blood and body fluids.
3. Place the patient in supine position.
4. Remove urostomy appliance.
5. Wash hands.
6. Apply sterile gloves.
7. Clean stoma with cleansing solution using a circular motion at the center of the stoma and moving outward.
8. Dry stoma with sterile gauze.
9. Lubricate catheter tip, and gently insert the catheter into the stoma approximately 2–3 inches. Do not force the catheter if resistance is met. Use a rotating motion to advance the catheter.

10. Continue to hold catheter in position until urine sample is removed.
11. If placing catheter for stomal stenosis, secure a silk suture around the catheter, and consider skin stitch or secure silk suture to urostomy appliance.
12. Clean and dry stoma and skin before securing urostomy appliance.

If ureteral stents are present:

1. Obtain consent from the patient. Discuss the risks and benefits of the procedure. Ensure all questions are answered.
2. Use universal precautions for protection against blood and body fluids.
3. Place the patient in supine position.
4. Remove urostomy appliance.
5. Wash hands.
6. Apply sterile gloves.
7. Trim ureteral stent tips.
8. Cleanse the ureteral stents with cleansing solution.
9. Dry stents with sterile gauze.
10. Attach 10 cc syringe to needleless med prep cannula.
11. Insert med prep cannula into tip of stent and aspirate urine. See Reference photo below.
12. IF stents are not draining, you can flush stents with 5 cc of sterile saline through med prep cannula and aspirate to assess return.
13. Urine can also be allowed to passively drip from stents into a sterile collection cup.
14. Clean and dry stoma and skin before securing urostomy appliance [4].

Complications

Complications may include bleeding, infection, or damage to conduit.

Keys to Success, Perils, and Pitfalls

- Consider using a least a 16 French-sized catheter for placement to allow for mucous drainage.
- While placing the catheter, a rotating technique can be used.
- If a 16F catheter is not able to be passed secondary to stenosis, consider trial with a 12 or 14 French catheter. Gentle dilation at the skin is acceptable [4].

CPT Coding

- 53670 Simple Catheterization
- 53673 Complex Catheterization

Summary

An ileal conduit is the most common urinary diversion choice. Urinary diversion is indicated in patients after cystectomy, because of bladder disease, bladder dysfunction, or inadequate urine storage resulting in incontinence. The ileal conduit is the simplest diversion to perform and is associated with the least postoperative complications. Despite this, patients are at long-term risk for urinary tract infection, stone formation, and stomal stenosis [5]. Patients suspected of having a urinary tract infection should have a specimen obtained for culture. In addition, external stoma complication rates can range between 15% and 65% and can sometimes be addressed with gentle dilation and placement of a catheter into the stoma.

Indiana Pouch/Mitrofanoff

Catheterization of Continent Catheterizable Pouches

Introduction

There are various techniques used to construct a continent urinary diversion that precludes the need for urine collection bag on the outside of the body. These diversions are typically made up of a ureterointestinal anastomosis, a reservoir for urine, and a conduit carrying urine from the reservoir to the skin surface [3]. Continent urinary diversion pouch options include the Indiana, modified Kock pouch, Mitrofanoff, Miami, and Mainz. The stomal location for access to these pouches is typically at the umbilicus or in the lower quadrant of the abdomen.

The Indiana pouch is a continent urinary diversion using the ascending colon and the ileocecal valve as the continence mechanism. The Mitrofanoff procedure and its variants use possibly part of the bladder and/or small intestine with the appendix used for continence mecha-

nism. The average capacity of an Indiana pouch is approximately 400–500 cc. This diversion type requires intermittent catheterization every 4–5 hours to drain urine and intermittent irrigation to clear mucous. Initially, after creation, the pouch should be irrigated more frequently with 50–60 cc of normal saline for mucous clearance [5].

Urinary retention is an emergency in this patient population. Patients are instructed to seek immediate medical attention for assistance with catheterization and drainage of their pouch. Retention can be manifested as inability for the patient to pass a catheter after a 6-hour period. This may be associated with abdominal pressure or pain [5].

Indications

- Urinary retention
- Urine culture collection

Contraindications

Relative contraindications may include an uncooperative patient. Patients with a suspected large pouch rupture should be surgically explored and repaired [5].

Risks/Benefits

Risk may include hematuria, infection, pain, and damage to the catheterizable channel or pouch.

Benefits may include improved pain control, relief of urinary obstruction, improvement in renal function, preserving pouch compliance, reducing risk of pouch rupture, and drainage of urine for specimen or monitoring of urine output.

Preparation

Supplies

1. Lubrication
2. 14–16 F coude catheter
3. 3 cc sterile water syringe
4. Urinary drainage bag

Procedure

1. Obtain consent from patient. Discuss the risks and benefits of the procedure. Ensure all questions are answered.
2. Use universal precautions for protection against blood and body fluids.
3. Place the patient in supine position.
4. Prep with topical antiseptic wipe.
5. Prep catheter with water-soluble lubricant.
6. Insert catheter into tract and follow path until urine is returned.
7. If resistance is encountered, redirect catheter tip.
8. If catheter is unable to be placed, notify urology team for possible cystoscopic placement of catheter.
9. If urine is returned, continue to advance the catheter.
10. Fill balloon port with 3 cc of sterile water and secure catheter in place.

Keys to Success, Perils, and Pitfalls

- A coude-tipped catheter may be helpful for placement.
- If resistance is encountered, re-direct the catheter.
- A smaller 12 French catheter can also be trialed.
- If unable to place the catheter, a cystoscopic approach may be required, and consult the urology team.

CPT Coding

- 53670 Simple catheterization
- 53673 Complex catheterization

Summary

There are various techniques used to construct a continent urinary diversion. Although infrequent, urinary retention in this patient population is an emergency, and catheter placement should be attempted using aseptic technique [5].

Neobladder

Catheterization of a Neobladder

Introduction

Urinary diversion types fall into three different categories, the ileal conduit, a continent cutaneous diversion, and more recently an orthotopic diversion. Orthotopic neobladder is an optimal choice for some patients as it most closely resembles the original bladder function and location. Voiding is accomplished by relaxing the pelvic floor and applying intra-abdominal pressure with a Valsalva maneuver. Most patients will be able to void to completion without the need for catheterization. The mechanism for urinary control to prevent urinary incontinence relies on the rhabdosphincter. There are several different procedure types that utilize different segments of the bowel as a reservoir. The best physiologic choices are made from the ileum or a combination of ileum and colon. This type of urinary diversion is reserved for a specific subset of patients. Contraindications for this diversion would include poor renal function, older age, obesity, and history of pelvic radiation. Typically, patients develop control of urinary continence 3–6 months after surgery. Approximately 10% of men and 60% of women fail to empty effectively leading to urinary retention [6].

Indications

Bladder catheterization may be needed for acute urinary retention, collection of a sterile urine specimen, monitoring of urine output, patient comfort in the terminally ill, and skin breakdown associated with urinary incontinence or for irrigation and mucous [2].

Contraindications

Relative contraindications may include an uncooperative patient, a suspected urethral disruption, or extensive pelvic trauma [2].

Risks/Benefits

Risks would include infection, pain, urethral injury, gross hematuria, urinary urgency, and frequency.

Benefits could include resolution of urinary retention, resolution of discomfort, improved renal function, and improved monitoring of urinary output.

Preparation

Equipment

- Foley catheter 16 or 18 French silicone or silicone coated
- Water-soluble lubricant or 2% lidocaine jelly with applicator
- Sterile towels
- Sterile gloves
- Betadine and cotton swabs
- 10 cc syringe with sterile water
- Urinary drainage bag

Procedure

1. Obtain consent from patient. Discuss the risks and benefits of the procedure. Ensure all questions are answered.
2. Use universal precautions for protection against blood and body fluids.
3. Place the patient in supine position for men and lithotomy position for female patients.
4. Prep and drape perineal area with Betadine.
5. If using, apply 2% lidocaine jelly into urethral opening using applicator, and leave in place for 5–10 minutes.
6. With the non-dominant hand, apply traction to visualize the urethral entrance on female patients.
7. Using the dominant hand, insert the full length of the Foley catheter into the neobladder until the junction of the balloon port.
8. Inflate the balloon port with 10 cc of sterile water.
9. Apply gentle tension, and pull catheter down until the balloon is against the bladder neck [2].

Complications

2. Hematuria
3. Urethral stricture
4. Urinary tract infection, pyelonephritis, urosepsis, or epididymitis
5. False passage creation or perforation [2]

Keys to Success, Perils, and Pitfalls

2. If urine does not flow freely after catheter placement, consider using a toomey syringe and 30–60 cc of normal saline to flush the catheter and ensure placement and patency of catheter. Lubricant jelly can clog the outlet of urine.
3. Once in place, secure the catheter to the patient with a leg strap to prevent additional trauma if catheter is tugged.
4. If catheter is not easily passed, request urology consultation [2].

CPT Coding

- 51701 Placement of a non-dwelling catheter into the bladder
- 51702 Simple placement of a bladder catheter
- 51703 Complex placement of a bladder catheter

Summary

Providers may encounter patients with orthotopic neobladder urinary diversions on patients with history of urologic malignancy requiring cystectomy and urinary diversion. Patient catheterization should be considered on patients if indicated and should be approached using sterile technique as noted above.

Bladder Trauma

Irrigation for Bladder Trauma

Introduction

Bladder injury is invariably associated with pelvic fractures. Approximately 75–95% of bladder ruptures have an associated pelvic fracture, although not all pelvic fractures have an associated bladder rupture (5–10%) [7]. Identification of bladder trauma can be made cystoscopically or via CT cystography, if assessing for a mucosal injury and perforation, respectively. Bladder injury can be suspected by evidence of gross hematuria; however, urethral injury should also be ruled out.

(a) If bladder trauma is suspected, a Foley catheter should be placed, preferably by a urology provider. If no urology provider is immediately available, atraumatic attempts, meaning non-forced insertion, can be attempted but should be aborted immediately if resistance is felt. The ideal Foley catheter size is at least a 20 Fr catheter. It must be a large-bore catheter!

(b) Duration of catheter after a bladder perforation is recommended to be approx. 14 days. Prior to removal, imaging should be done to ensure that the injury is well healed.

CT cystogram is performed to assess for any extravasation of contrast from the bladder's lumen. Estimated sensitivity and specificity is around 95–100%. Conventional x-ray cystography may alternatively be ordered by urology and has an estimated 85–100% sensitivity and specificity [7] (Fig. 36.3a, b).

Indications

- Gross hematuria, radiographic extravasation on cystogram, and clot retention

Contraindications

Organized in situ bladder clot (CBI) and bladder cancer with a known bladder perforation. Consult urology for management.

Risks/Benefits

Ensuring continued drainage or flow prevents obstructive uropathy/renal failure. Furthermore, irrigation can prevent precipitation of clots within the bladder by evacuating any residual blood.

Manual irrigation with flushing of catheter using sterile saline can be uncomfortable to the sensate patient as the bladder is filled to its maximum compliance. Furthermore, manual irrigation can also stimulate the pelvic plexus resulting in a bowel movement. Patient comfort should be considered when performing manual irrigation.

Preparation

Sterility is always important when planning to instill a fluid/solution within the bladder cavity,

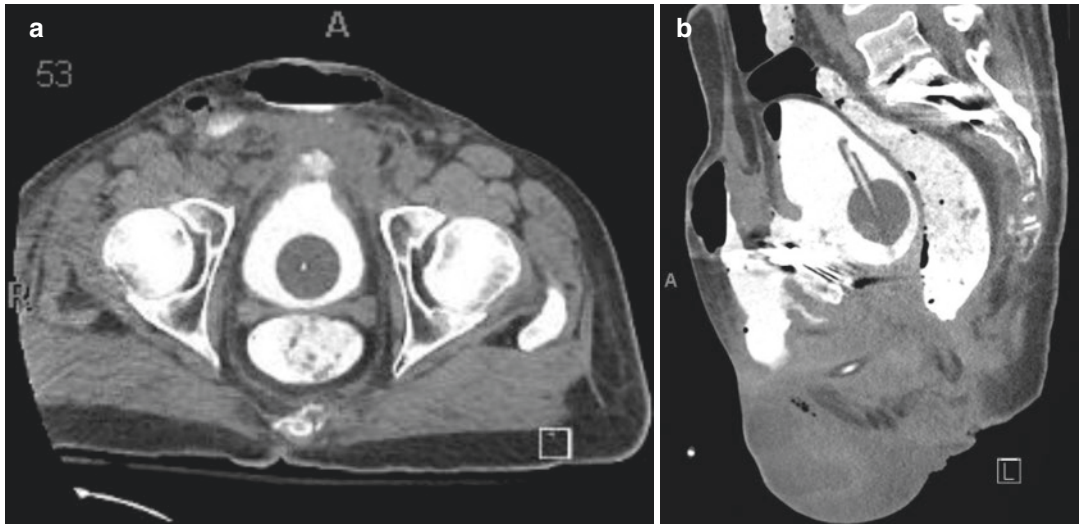

Fig. 36.3 (**a**, **b**) CT cystogram demonstrating anterior bladder wall rupture. Rupture ultimately required explant of prior pelvic prosthesis

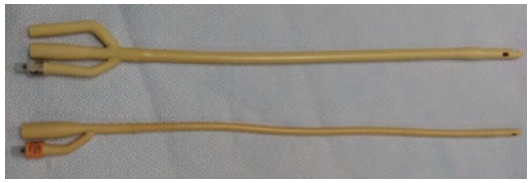

Fig. 36.4 24 Fr three-way catheter lying above a standard 16 Fr two-way catheter for comparison

so the clinician or provider should attempt to take associate measures; however, aseptic technique should not delay a necessary intervention if retention is causing severe obstructive renal failure.

Appropriate supplies for irrigation:

- Manual/intermittent – toomey or piston syringe (60 cc syringe with tapered tip; not twistable stopcock!), 1 L bottle of sterile saline/water (saline preferred), and beaker for waste
- Continuous bladder irrigation – Hangable 3L 0.9% NS instillation bag, irrigation tubing, and a three-way hematuria catheter.

CBI for hematuria/trauma should not be utilized any catheters smaller than 20 Fr (Fig. 36.4).

Procedure

Manual/intermittent irrigation:

1. Disconnect the patient's catheter from the drainage bag. Placing the end of the tubing that connects to the drainage bag in a sterile cup or wrapped in a sterile towel will ensure that there is no leak or soilage while disconnected.
2. Draw back 60 cc of sterile saline into the piston syringe.
3. Insert the piston syringe directly into the main catheter port!
   (a) Do not insert into the additional port of a three-way catheter used for continuous bladder irrigation, as the third port allows for instillation, but is not large enough for aspiration of clots/hematuria.
4. Inject the 60 cc, and then pinch off the catheter to ensure that instilled saline remains within the bladder.
5. Withdraw another 60 cc of sterile saline, and again instill the saline into the bladder.
   (a) With 120 cc of saline in the bladder, the bladder should be relatively distended to allow for aspiration that is not impeded by

redundant bladder mucosa lying over the eyelets on the catheter's tip.

(b) You may skip the additional 60 cc, in patients who already have a confirmed large volume of fluid within their bladder (confirmed on prior radiographic or sonographic imaging).

6. Begin aspiration of the bladder's contents.
   (a) You may desire to create turbidity in the bladder by instilling and aspirating back repeatedly in order to break up any clots.
   (b) Any clots aspirated should be wasted in a separate canister from the sterile irrigant.
   (c) Aspiration and irrigation should be carried out with a goal of clearing the urine. Urine output does not need to be clear yellow but ideally a clear pink consistency to prevent clot formation.

Troubleshooting

Not being able to aspirate back any fluid:

1. Manipulate the catheter. Gently hub the catheter at the meatus, and re-attempt aspiration. Additionally, rotate the catheter so that the tip turns inside the bladder to ensure that you are not aspirating on the bladder wall.
2. Instill an additional 60 cc, or a smaller volume (10–30 cc), if the bladder is already distended, to clear the catheter, and then re-attempt aspiration.
3. Contact urology. The catheter may require more precise troubleshooting, a possible exchange for a brand new Foley catheter, or worst-case scenario a trip to the OR to evacuate an organized obstructing clot.

Continuous bladder irrigation:

1. In a patient who has a three-way urethral catheter, and likely already has the third port (typically on the right or left; the middle port is the drainage port and a much bigger lumen) plugged, gather your supplies.
2. You will need to hang the irrigation fluid, ideally on an IV pole, but somewhere above the patient's head.
3. The irrigation bag should be spike, and the tubing should be primed (getting the air out) by allowing for the fluid to run just out of the end.
4. Next, insert the irrigation tubing into the third port of the patient's catheter. Ensure that the connection is good; sometimes you may have to remove the silicone connect to expose the tapered plastic of the irrigation tubing for insertion (dependent upon manufacture).
5. Once the tubing is primed and connected to the patient's Foley catheter, begin infusion. Initially, it is preferred to run the CBI "wide open" to assess the degree of hematuria. Running the CBI to maximum gravity allows for the drainage to be primarily irrigant. If there is still hematuria with the drip running wide open, it is a bad prognostic sign (may be a severe bleed or organized clot within the bladder causing the discoloration of the urine. Manually irrigate Foley to diagnose the issue).
6. Adjust/titrate the drip rate to a clear pink output. The nurse should be left in charge of this after initial setup, because hematuria can wax and wane with patient movement.

Complications

Complications are rare with bladder irrigation, however, can and do result. Risk of bladder perforation is possible in patients on continuous bladder irrigation. The bedside clinician must be vigilant in ongoing assessments for decreasing drainage via Foley catheter, reports of bladder fullness, or significant clots seen in catheter tubing. If these situations arise, the initial response should be immediate discontinuation of the continuous drip. The clinician should then proceed with manual aspiration, just enough irrigation to clear any obstruction, and notify the urology service.

Keys to Success, Perils, and Pitfalls

As previously stated in the procedure section, manipulating the catheter increases the likelihood of being successful with manual irrigation. "Hubbing" the catheter at the meatus and rotating the catheter, either clockwise or counter clockwise, can help with outward flow.

CPT Coding

- CPT code 51700 – Simple bladder irrigation, lavage, and/or installation

Summary

Bladder irrigation is an important and vital procedure in patients who suffer bladder trauma. Proper technique of irrigation is incredibly important to preserve bladder health and prevent bladder injury.

Additional Resources

The American Urologic Association has a library worth of information on catheterization and by default bladder irrigation.

Example

https://www.auanet.org/education/auauniversity/for-medical-students/medical-students-curriculum/medical-student-curriculum/bladder-drainage

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Suggested Readings

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Miscellaneous Urologic Problems

37

Jaclyn M. Mieczkowski, Abby Looper,
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Priapism (Figs. 37.1 and 37.2)

Introduction

A priapism is characterized as an erection of the penis lasting greater than 4 hours unrelated to sexual stimuli. This diagnosis can be divided into two categories, low-flow ischemic priapism and high-flow non-ischemic priapism. The most common variant is ischemic low flow with patients presenting to providers with venous engorgement of the penis and pain requiring emergent treatment. The corpora cavernosa becomes engorged with poorly oxygenated blood. This can be caused by either obstruction of venous flow or penile muscle tissue inability to adequately contract and assist with venous blood outflow. High-flow variants are much less common and not always associated with pain [1]. These two variants can be distinguished using a blood gas obtained from the corpora. A low-flow priapism would have PO2 less than 30 mmHg, PCo2 > 60 mmHg, and pH < 7.25. A perineal Doppler ultrasound may also be helpful to distinguish high-flow priapism [2].

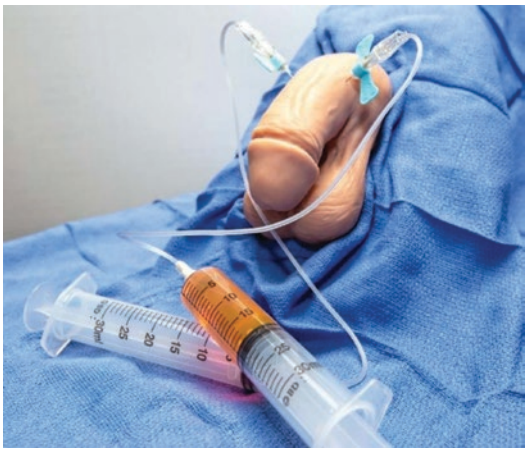

Fig. 37.1 25 Butterfly needle insertion technique for aspiration and flushing. (Photography Credit: Phillip Hernandez)

Priapism can be associated with sickle cell disease, diabetes, cocaine use, hematologic malignancies, stoke, and use of erectile dysfunction medications, both oral agents like sildenafil and tadalafil, and intra-cavernosal injection medications like papaverine, prostaglandin, and phentolamine. Other oral medications may also contribute to priapism including anticoagulants (heparin/warfarin), anti-hypertension medications (hydralazine/doxazosin), and antipsychotics (trazodone/fluoxetine/citalopram), hormones (testosterone), and other agents like general anesthesia or TPN [1].

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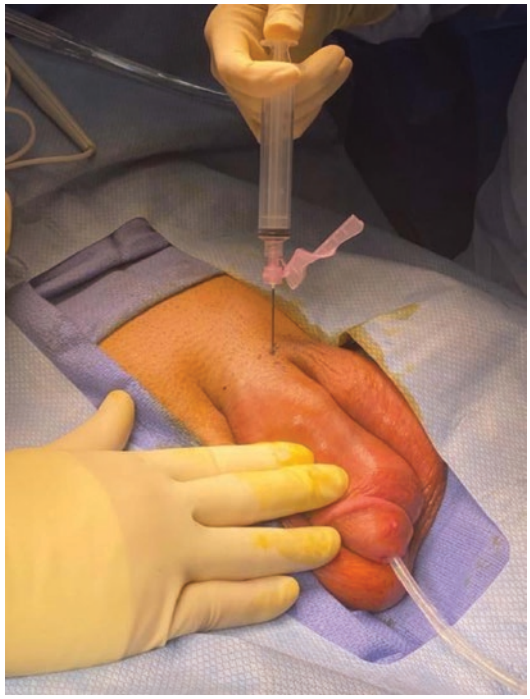

Fig. 37.2 Penile block with lidocaine along the dotted line at base of penis. (Photography Credit: Phillip Hernandez)

Indications

If patient fails conservative management with oral or subcutaneous terbutaline, attempted intracorporal phenylephrine injection should be utilized via three doses given every 20 minutes. If this is not successful, it should be followed by aspiration of corporal blood. If still unsuccessful, urology should be consulted for possible irrigation of corporal body with diluted alpha-adrenergic agonist solution and, ultimately, possible shunt placement [1].

Contraindications

A stuttering priapism, most often seen in sickle cell patients and characterized by recurrent episodes of priapism lasting less than 3 hours, does not always require intervention. Consider emergent management only in prolonged priapism episodes. A high-flow non-ischemic priapism should be treated surgically [1].

Risks/Benefits

Benefits include resolution of pain associated with priapism and preservation of erectile function. Risks of procedure may include hematoma, pain, infection, damage to surrounding structures, erectile dysfunction, and Peyronie's disease [1].

Preparation

Supplies:

1. Sterile drapes
2. 1% lidocaine for penile block
3. 27-gauge needle attached to 1 mL syringe for penile block
4. Betadine or chlorhexidine solution
5. 19-gauge butterfly needle
6. Gauze
7. 10 mL syringe (2)
8. 30 mL syringe (2)
9. Basin for collection of aspirated blood
10. Irrigation fluid administered in 20–30 mL at a time
    (a) Phenylephrine 10 mg/500 mL normal saline [1]

Procedure

1. Obtain patient informed consent for procedure. Explain the risks and benefits of the intervention, and ensure all questions are answered appropriately.
2. Place patient on telemetry monitoring.
3. Position patient supine with penis exposed.
4. Consider administering parenteral narcotic for patient comfort.
5. Prep the penis with Betadine or chlorhexidine solution and drape.
6. Use lidocaine anesthesia at puncture sites.
7. A penile block can be administered using 1% lidocaine.
   (a) Dorsal penile block with lidocaine injected at the base of the penis
   (b) Circumferential penile block

8. Draw up 0.5 mg of phenylephrine (0.5 mL), and add 0.5 mL of normal saline to dilute the solution in a 1 mL tuberculin syringe.
9. Inject corpus with vasoactive agent using a 25–27-gauge needle at the 10 and 2 o'clock position at the base of the penis approximately 2–4 cm distal to the shaft origin. Aspirate blood prior to injection to confirm position. Only one side needs to be injected. Wait 20–30 minutes between each injection with a max of three administrations.
10. If unsuccessful, proceed to corporal aspiration.
11. Place a 21–19-gauge butterfly needle at 2 and 10 o'clock in the corpus cavernosum. Site can be located 2–4 cm distal to the shaft origin. Do not puncture the glans. See reference picture below.
12. Using constant suction, the needle should be advanced at a 45-degree angle. Once blood is returned, do not further advance the needle. Stabilize the needle to prevent deeper penetration and injury.
13. Using a 10 or 20 cc syringe, aspirate 20–30 mL of blood and milk to corpus with other hand.
14. Continue aspiration of blood until it becomes bright red and arterial in color and complete detumescence persists.
15. If this process is unsuccessful, proceed to irrigation with diluted vasoactive solution.
16. Solution: 10 mg phenylephrine in 500 mL of normal saline. Irrigate with 20–30 cc of this solution using a syringe attached to butterfly needles, and aspirate fluid and blood between administration.
17. If success is not achieved, patient may require additional surgical intervention with shut.
18. If successful detumescence occurs, patient should be observed for at least 2 hours. The penis should be wrapped with gauze and loosely with an elastic bandage to help reduce risk of hematoma [1].

Complications

1. Hematoma
2. Infection
3. Systemic absorption of phenylephrine
4. Impotence
5. Pain, if unsuccessful nerve block [1]

Keys to Success, Perils, and Pitfalls

1. When aspirating blood from the corpus, use a 10 cc syringe instead of a larger volume as the additional suction of a 60 cc syringe may cause excessive suction and reduce aspiration efforts.
2. Using a butterfly needle can help reduce the chance of accidental dislodgement of the needle [1].
3. Penile blocks can be administered with 27-gauge needle at the base of the penis by slowly inserting the needle at the 2 and 10 o'clock position until resistance is noted. This should be Buck's fascia. The syringe should be aspirated to assess if the needle is within a blood vessel. 2 mL of lidocaine should be administered to each side. Do not use lidocaine with epinephrine [3].

CPT Coding

- 54220 Irrigation of corpora cavernosa
- 54235 Injection of the corpora cavernosa with pharmacologic agent

Summary

Prolonged priapism can contribute to pain and long-term erectile dysfunction and should be aggressively managed. If an erection lasts longer than 4 hours, conservative measures should be utilized initially followed by injection of vasoactive agents with or without aspiration [1].

Ureteral Stent Care and Removal via Dangler Suture

Ureteral Stent Care and Removal

Introduction

A ureteral stent (also called DJ, JJ, or double J stent) is a long, slender, hollow tube that traverses the entire length of the ureter with double pigtails (hence the double J terminology) at either end of the stent. These are typically placed intraoperatively for the following purposes: to re-establish or maintain the patency of the ureter after kidney stone removal, to treat a ureteral stricture, and to alleviate extrinsic ureteral compression (usually due to intra-abdominal malignant processes or retroperitoneal fibrosis). Common side effects and risks of these stents include bladder spasms (due to irritation of the bladder wall), hematuria, vesicoureteral reflux, infection, and encrustation [4]. Occasionally, a dangler suture may be left on the distal curl of the JJ stent, which may be seen exiting the urethral meatus. Should a ureteral stent need to be a more permanent solution, stents may be left in place for a maximum of 3 months before they need to be exchanged.

Indications

- Ureteral stent removal

Contraindications

- Untreated UTI
- Removal sooner than the previously determined date by the urology provider

Risks/Benefits

Removal of a ureteral stent via a dangler suture is less invasive than removal utilizing cystoscope and graspers.

Preparation

First, ensure that the stent is supposed to be removed. This is decided at the discretion of the urology provider and is based upon various factors. The intended date of removal of the stent is typically pre-determined and listed at the time of stent insertion.

If it is not time to remove the stent, care must be taken to avoid accidentally dislodging or removing the stent. The string may be loosely taped to the mons pubis in females or the shaft of the dorsal penis in males to help secure it.

To remove the stent, first don clean gloves. Position the patient lying supine on an exam table or bed with legs in flexed position or in stirrups.

Procedure

Grasp the dangler suture string with clean, gloved hand, and pull in a steady fashion until the entire stent has been removed (this takes approximately 5 seconds).

Keys to Success, Perils, and Pitfalls

Pain relief medications (NSAIDs, narcotics) or anticholinergics (i.e., oxybutynin) may be given 30 minutes prior to stent removal to help reduce bladder spasms and discomfort.

If you find that the stent has been removed prematurely, immediately contact the urology team to determine if another stent needs to be replaced immediately or if the patient will just require sooner imaging follow-up.

CPT Coding

- None

Summary

Ureteral stents are long, hollow tubes that traverse the entire ureter and are commonly used after stone removal and for treatment of ureteral strictures and extrinsic ureteral compression. These tubes are typically only a temporary solution, such as after stone surgery, but others may be a permanent part of the patient's management plan; therefore, it is imperative you confirm with the urology team that the stent is supposed to be removed before proceeding. To remove the stent, you simply grasp the dangler suture exiting the urethral meatus with a clean, gloved hand and pull in a steady fashion for approximately 5 seconds until the entire stent is removed intact.

PCN Care, Irrigation, Removal

Percutaneous Nephrostomy (PCN) Tube Care, Irrigation, Removal
(Fig. 37.3a,b)

Introduction
- A percutaneous nephrostomy tube is a catheter placed into the collecting system (either in interventional radiology or in the operating room) to provide urinary drainage and/or relieve ureteral obstruction. There are two types of PCN tubes: pigtail and wide bore (either Malecot or Foley catheter) [5].

General care for these tubes includes the following: (1) ensuring the tube is connected to a closed drainage system; (2) the drainage bag should be below the level of the kidney; (3) there is no kinking in the tubing; and (4) the tube is well-secured to prevent dislodgement.

Indications
- Irrigation: absence of urine in the drainage tubing, persistent hematuria, suspected blockage, and flank pain

Contraindications
Removal of the PCN tube should *not* be performed unless ordered by the urology provider. An antegrade nephrostogram is sometimes required prior to removal in order to ensure there is good forward flow in the ureter.

Preparation
Position patient prone on exam table or bed. Don clean gloves.

Procedure

Irrigation
- Assemble alcohol wipes and 10 mL saline flushes.
- Clean the irrigation port by wiping it with alcohol pad for 10 seconds. Attach the prefilled syringe with normal saline. Position the stopcock and the opening port so that the opening is toward the patient. Briskly push 5 mL of the fluid through the tubing. Reposition the stopcock so that the opening port is away from the patient. Briskly push 5 mL of fluid through the tubing. Do *not* force if resistance is encountered. Rotate the stopcock back to closed [5].

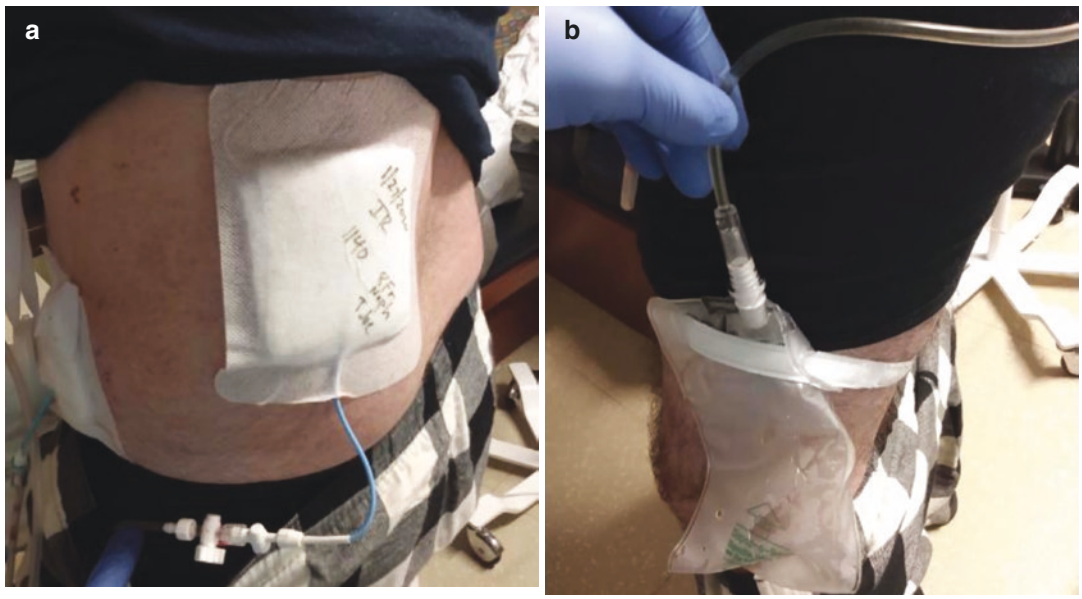

Fig. 37.3 (**a**, **b**) Patient with left side percutaneous nephrostomy tube connected to leg bag for discharge

Removal

- Cut the skin suture that secures the tube to the skin, and then cut the tube (this releases the retention string inside the pigtail to allow it to uncoil). Gently pull until the entire tube until it has been removed. Apply dressing to drainage site.

Keys to Success, Perils, and Pitfalls

It is common for PCN site to drain small amounts of fluid for the first 24–48 hours after PCN removal. Keeping a dry dressing over the site can help manage this. If the output is persistent and/or patient experiences flank pain or reduced urine output after removal, the ureteral flow may not be sufficient, and the urology team should be contacted.

Summary

Management of PCN tubes in the ICU may involve irrigation or removal, as instructed by the urology team.

Scrotal Edema

Scrotal edema and swelling is a complication that may develop in hospitalized male patients, particularly with history of debilitation, heart failure, and other conditions associated with fluid overload. It is important to differentiate scrotal edema from an acute scrotum (such as that associated with testicular torsion, Fournier gangrene, epididymo-orchitis, hernia). If there is clinical concern, testicular ultrasound is indicated.

Benign scrotal edema in the ICU patient can cause pain and skin breakdown. It can also be distressing to the patient and their family. Treatment usually includes fluid management and scrotal elevation. Scrotal elevation may be achieved with scrotal support with a jock strap in the ambulatory patient and/or a rolled towel placed under the scrotum in an immobile patient [6].

Scrotal Abscess (Fig. 37.4)

Introduction

Abscesses located in the scrotal and perineal area are usually associated with sebaceous cyst, folliculitis, and lacerations or associated with prior scrotal surgeries [7]. However, a patient may also have an intra-scrotal process associated with epididymitis, appendicitis-related drainage, or urethra stricture associated with leakage of infected urine. A severe manifestation, such as Fournier gangrene, can also involve the scrotal tissue requiring more aggressive intervention [8].

Initial evaluation should include a thorough history followed by physical exam of the scrotum. Patients may complain of symptoms associated with the source of abscess. Urinary tract infection or STD symptoms could include uri-

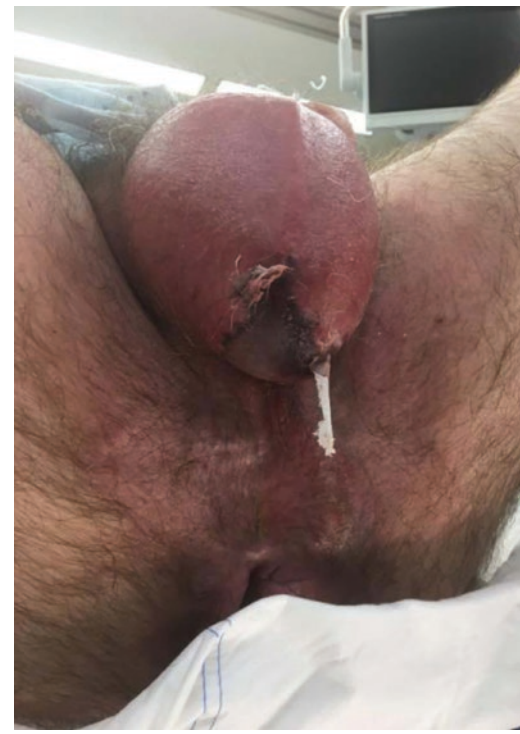

Fig. 37.4 Fournier gangrene patient with need for OR debridement and excision. Not suitable for bedside I&D

nary frequency, burning with urination, and penile drainage. On exam, the scrotum may be tender and edematous with erythema. Fluctuance may be palpable on exam [8]. To rule out other acute processes like a peri-rectal abscess or Fournier gangrene, imaging with pelvic CT or scrotal ultrasound may be indicated [7]. On scrotal ultrasound, an abscess would appear as a discrete fluid collection, possibly with gas.

Treatment of a scrotal abscess should include antibiotic coverage with an appropriate antibiotic such as a cephalosporin and incision and drainage of the abscess pocket [7]. The abscess cavity should remain open and packed. A diagnosis of Fournier gangrene would require aggressive management with surgical debridement and antibiotic regimen [8].

Indications

If spontaneous drainage of scrotal abscess is not elicited, then bedside incision and drainage of a loculated fluid collection should be considered [7]. Only superficial scrotal abscess noted to the scrotal wall without intra-scrotal penetration should be attempted at bedside. An intra-scrotal abscess evacuation would typically be managed under general anesthesia [8].

Contraindications

Bedside scrotal abscess incision and drainage should not be considered in suspected cases of Fournier gangrene. This disease process involves necrotizing fasciitis of the male perineal area and genitalia and should be explored in the operating room for adequate debridement of affected tissue [7].

Risks/Benefits

Risks of this procedure may include pain, bleeding, incomplete evacuation of abscess requiring additional procedure, or damage to scrotal contents, sequelae of epididymitis [8].

Benefits of this procedure may include improved pain, resolution of abscess, and prevention of worsening symptoms such as cellulitis, sepsis, and fistula formation [8].

Preparation

Supplies

- Local anesthetic (lidocaine 1% or 2%)
- 25–30-gauge needle, 0.5–1 inch
- 10 cc syringe
- Chlorhexidine swab or stick or Betadine
- 11-inch blade
- Gauze
- Forceps/pick-ups
- Scissors
- Cotton-tipped swabs
- Hemostat
- Packing: iodoform gauze, ¼ inch or 1/2inch
- 10 cc saline syringe for irrigation
- Draping material such as blue OR towels
- Razor for removal of scrotal hair if needed
- [9]

Procedure

Preparation

1. Obtain informed consent from the patient. Explain the risks and benefits associated with this procedure, and ensure all patient questions are answered.
2. Shave scrotal hair if needed for better visualization.
3. Use universal precautions including gloves and eye protection as abscess contents can eject when pressure is applied.
4. Position patient supine with abscess tissue exposed; consider lithotomy if needed.
5. Ensure adequate lighting.
6. Drape the area of abscess.
7. Prep the tissue with chlorhexidine or Betadine stick.
8. Apply a field block with lidocaine around the perimeter of the abscess.
9. With a blade, make an incision into the apex of the abscess approximately 1–2 inches in

length pending the size of abscess to give adequate exposure.
10. Apply pressure to fluid pocket to expel purulent contents.
11. Use hemostats or cotton-tipped applicator to explore abscess and open additional loculated pockets of contents.
12. Once purulent fluid has been adequately evacuated, use forceps and cotton-tipped applicator to insert gauze into the abscess cavity. Enough gauze should be applied to fill the space and a tail of gauze cut at the skin for allow for exchange [9].

Complications

Complications could include:

1. Keloid or scar tissue
2. Reoccurrence of abscess if incompletely drained
3. Progression to cellulitis, sepsis, or Fournier gangrene
4. Fistula

[9]

Keys to Success, Perils, and Pitfalls

- The patient should be positioned adequately to ensure appropriate exposure. Consider additional assistance to hold the scrotum during procedure.
- Consider additional lidocaine as needed for patient comfort as the acidic nature of abscess contents lessens the effects of anesthetic.
- Ensure the incision is large enough to sufficiently evaluate the pocket and remove contents.
- To obtain a specimen, do not collect from the superficial area. Consider aspirating fluid contents with a syringe prior to incision, or collect a specimen after incision from a deeper pocket [9].

CPT Coding

- 10060 I & D abscess, non-complex
- 10061 I & D complex abscess or multiple abscesses
- 55100 I & D scrotal abscess
- [9]

Summary

Superficial scrotal abscess or infection at the level of the scrotal wall can be successfully managed with bedside incision and drainage with appropriate antibiotics [8].

Paraphimosis

Reduction of Paraphimosis

Introduction

Paraphimosis occurs when the foreskin of an uncircumcised male becomes trapped behind the glans penis. This leads to swelling of the glans [10]. The paraphimosis must quickly be reduced to prevent necrosis of the glans penis [11].

Indications

Paraphimosis is considered a medical emergency to prevent the restriction of blood flow to the glans penis.

Contraindications

- None

Risks/Benefits

Risks include inability to reduce the paraphimosis with ongoing restriction of blood flow to the glans penis, need for additional procedures, and pain.

Benefits include restoration of blood flow to the glans penis and resolution of pain.

Preparation

Supplies needed include lubricating jelly and gloves. Explain the procedure to the patient regarding necessity of procedure and expectations.

Procedure

Begin with the patient in the supine position. With gloves on hands, apply lubricating jelly to the glans penis. With the thumbs on the left and right sides of the glans penis, place the two fore fingers on the dorsal penis shaft just behind the glans penis and the two middle fingers on the ventral penile shaft just behind the glans [11] (Fig. 37.5).

While pushing with the thumbs, use the other four fingers to pull back on the foreskin to reduce the paraphimosis [11].

Complications

If the glans penis is significantly edematous, pressure may need to be applied to the glans penis to relieve swelling before the paraphimosis can be reduced [12].

Keys to Success, Perils, and Pitfalls

One hand can be used to squeeze the glans penis for 5 minutes to relieve swelling prior to reduction of the paraphimosis [12]. An alternative is to apply cling wrap to the glans and penile shaft for no more than 3–5 minutes to relieve the swelling. With removal of the cling wrap, immediately attempt reduction.

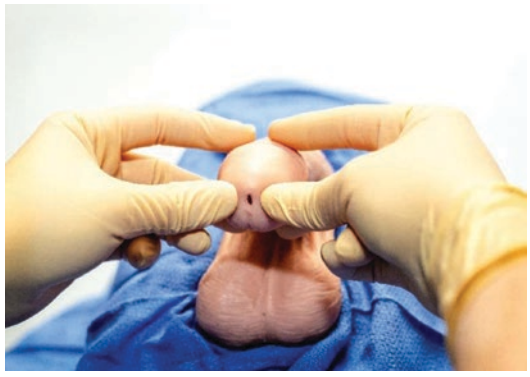

Fig. 37.5 Finger placement for reduction of paraphimosis

CPT Coding

- Slitting of prepuce, except newborn: 54001
- Circumcision: 54150

Summary

If repeated paraphimosis occurs or cannot be reduced, consider surgical intervention with dorsal slit at the bedside or circumcision in the operating room [12].

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Part VIII

Orthopedic Procedures

38 Fracture Management: Basic Principles, Immobilization, and Splinting

Maribeth Harrigan

Basic Fracture Principles

What is a fracture? A bone fracture is where the continuity of the bone is broken. Fractures can be classified as traumatic due to a trauma or pathological due to an underlying disease. Traumatic fractures are transverse, oblique, spiral, displaced, angulated, impacted, rotated, distracted, and comminuted. Basic principles to a fracture are reduction, immobilization, and rehabilitation. Reduction is properly aligning the fracture. Immobilization is keeping the alignment or preventing displacement for union of the fracture to occur. Rehabilitation is muscle re-education and gait training (if lower extremity fracture) which occurs after fracture healing [1] (Fig. 38.1).

Fracture Reduction

A fracture reduction can be done through closed manipulation, continuous traction, and open reduction. Reduction is specific for fracture location and pattern. The goal for reduction is to restore length, alignment, and rotation (Fig. 38.2a–c).

Reduction is performed with anesthesia or conscious sedation to help the muscles relax. A closed manipulation is re-aligning the fracture by feeling through soft tissues. A continuous traction reduction is re-aligning the fracture through a set of mechanisms for straightening the broken bone(s). An open reduction is re-alignment with a surgical fixation.

Principles of Immobilization

Immobilization can be achieved through strapping, sling use, splinting/casting, and functional bracing. Strapping is using an adjacent part of the body to stabilize the fracture. Sling is used to prevent further injury by immobilizing a joint. Splinting or casting is a rigid material used to help hold the fracture alignment. Functional bracing is a removable brace such as a boot or knee brace which allows continuous use of the affected limb while keeping the fracture adequately supported (Fig. 38.3a–d).

Principles of Splinting

The following are basic principles for splinting which are universally accepted:

1. Correct and prevent deformity.
2. Protect against further soft tissue damage.

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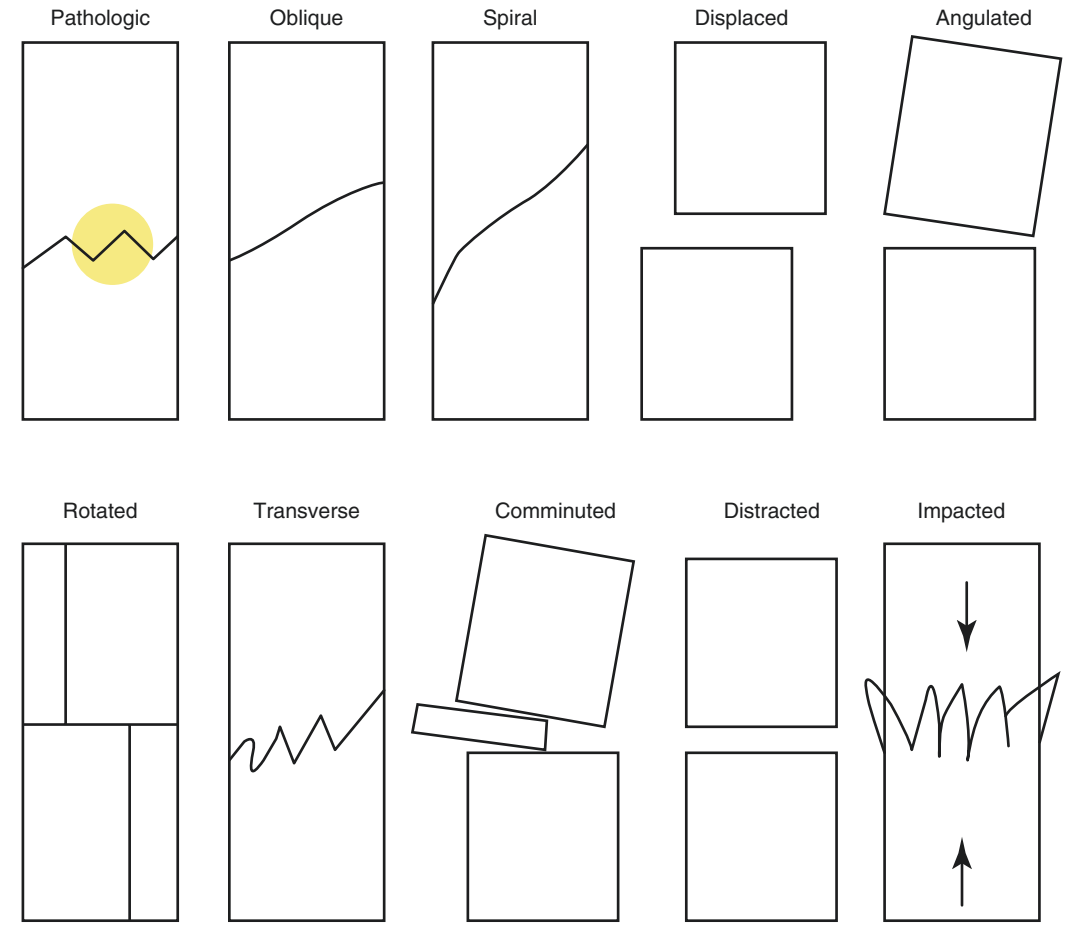

Fig. 38.1 Different types of fracture patterns

3. Immobilize fracture site or reduced dislocation.
4. Provide pain relief and assist with inflammatory process/edema resolution.

A thorough and complete physical examination, including appropriate review of necessary radiographs, is fundamental in diagnosis and determination of splinting needs. Once the fracture pattern is recognized, the skin and soft tissue have been evaluated, and appropriate analgesia is provided, the patient is ready for fracture or dislocation reduction and splinting [2].

Difference Between Splinting and Casting

Splints are non-circumferential immobilizers, therefore, being more forgiving and allowing for swelling in the acute phase. Splinting is useful for a variety of acute orthopedic conditions such as fractures, reduced joint dislocations, sprains, severe soft tissue injuries, and post-laceration repairs. The purpose of splinting acutely is to immobilize and protect the injured extremity, aid in healing, and lessen pain.

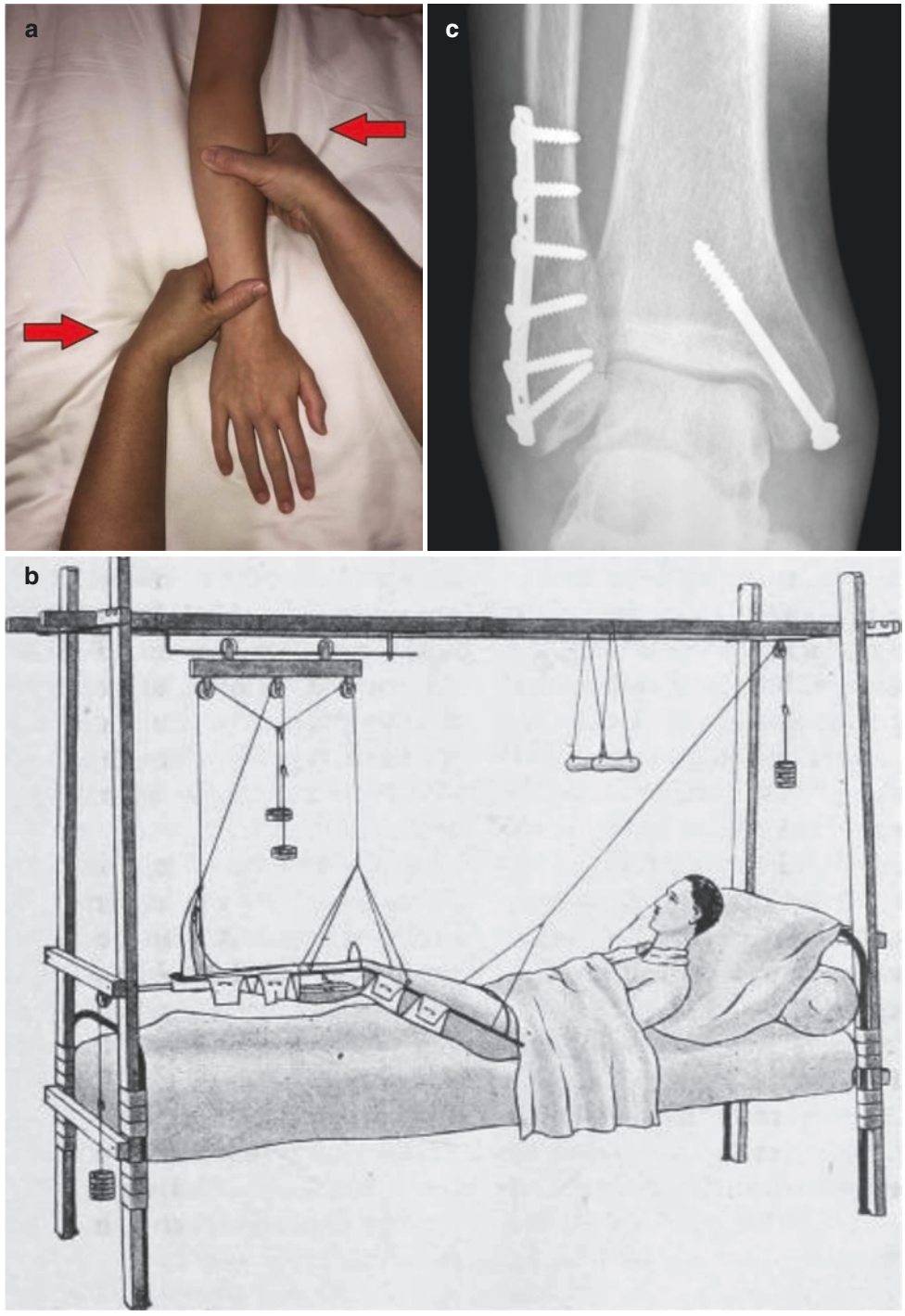

Fig. 38.2 (**a**) Closed manipulation; (**b**) continuous traction; (**c**) open reduction internal fixation (ORIF). **b**: (Reprinted from The Trained nurse and hospital review; New York, NY; 1888. Gerstein – University of Toronto. Retrieved from https://www.flickr.com/photos/internetarchivebookimages/14741206736.) **c**: (Reprinted from Wikimedia. Retrieved from: https://commons.wikimedia.org/wiki/File:Trimalleolar_Ankle_Fracture_Xray_shown_before_surgery_and_after_surgery.png. With permission from Creative Commons License 3.0: https://creativecommons.org/licenses/by-sa/3.0/deed.en)

Fig. 38.3 (**a**) Strapping; (**b**) sling; (**c**) casting; (**d**) functional bracing. **b**: (Reprinted from WikEM. Retrieved from: https://www.wikem.org/wiki/Sling_and_swathe_splint. With permission from Creative Commons License 4.0: https://creativecommons.org/licenses/by-sa/4.0/) **c**: (Reprinted from Pixabay. Retrieved from https://pixabay.com/illustrations/cast-plaster-cast-arm-in-a-cast-4360734/.) **d** (left): (Reprinted from Wikimedia. Retrieved from: https://commons.wikimedia.org/wiki/File:Hinged_Brace.png. With permission from Creative Commons License 4.0: https://creativecommons.org/licenses/by-sa/4.0/deed.en.) **d** (right): (Reprinted from Free-Images.com. Retrieved from: https://free-images.com/display/crutches_png.html)

Casting is a circumferential application of plaster or fiberglass to an extremity. Casts provide superior immobilization but are less forgiving and have higher complication rates. Therefore, they are usually reserved for complex and/or definitive fracture management [2].

Materials Needed for Splinting

Basic splinting materials include:

- *Basin or bucket with room temperature water*. The warmer the water, the faster the splint sets.
- *Stockinette.* A medical dressing applied prior to casting to provide extra cushioning around the edge of the cast.
- *Cast padding*. Utilized for skin protection and padding of bony prominences under splint material. When placed, it should overlap by 1/2 width to ensure total coverage of underlying skin. For splints, multiple layers are recommended.
- *Plaster*. Available in rolls or splint strips of varying widths. The material is made by impregnating crinoline with plaster of Paris. Once dipped into room temperature water, the powder forms a solid substance and releases heat (an exothermic reaction) during the setting process. Drying time varies by the number of layers used, water temperature, and room temperature [3]. The provider must be thorough in the process yet quick with the placement in order to assure desired position before the plaster hardens.
- *Fiberglass*. A lighter-weight product available in prefabricated rolls already padded. It can then be measured, cut, moistened per manufacture's instruction, and placed appropriately.
- *Bias wrap* or *ACE wrap*. A stretchable cloth material used as the final layer of the splint.
- *Tape*.
- *Trauma Shears*.

Application Techniques Used in Upper and Lower Extremity Splints

The actual order and process of splint placement is the same regardless of location or type.

1. Check neurovascular status and motor function for baseline.
2. Apply the stockinette to extend 2 inches beyond the splinting material at both ends.
3. Apply 2–3 layers of cast padding over the area to be splinted (and between digits being splinted). Add an extra 2–3 layers over bony prominences only.
4. Lightly moisten the splinting material. Place it and fold the ends of the stockinette over the splinting material.
5. Apply the bias wrap or ACE wrap. Apply tape to end of wrap.
6. Use palms to mold the splint to the desired shape; support while still wet.
7. Once hardened, check neurovascular status and motor function to confirm at baseline.

Common Splinting Techniques for the Upper Extremity [3–8]

Thumb Spica (Fig. 38.4)

- *Indications*—injuries for use include fracture or ligamentous injury to the thumb, first metacarpal, scaphoid, lunate, and radial styloid.

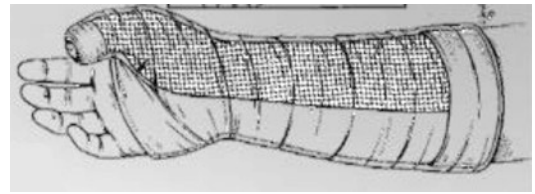

Fig. 38.4 Thumb spica splint. (Reprinted from WikEM. Retrieved from: https://wikem.org/wiki/Thumb_spica_splint. With permission from Creative Commons License 4.0: https://creativecommons.org/licenses/by-sa/4.0/)

- *Positioning*—abduct thumb (wineglass position) with hand and wrist in neutral position.
- *Application*—cut hole in stockinette for the thumb. Place cast padding from the level of the interphalangeal (IP) joint of the thumb to the proximal 1/3 of the forearm. Once full skin protection is ensured, take premeasured, wet, stripped plaster/fiberglass, and apply to radial border of thumb and forearm leaving IP joint of thumb free. Wrap plaster/fiberglass with bias/ACE distally from IP joint to proximal forearm. Tape to secure. Avoid wrapping too tightly. Ensure desired position and allow plaster/fiberglass to set.

Radial Gutter (Fig. 38.5)

- *Indications*—injuries for use include fractures of index and long finger and second and/or third metacarpal fractures.
- *Positioning*—extend wrist slightly with the metacarpophalangeal joints flexed 70–90° and the proximal interphalangeal and distal interphalangeal joint in 5–10° of flexion.
- *Technique*—place 4 × 4 gauze between index and long finger for webspace protection. Use cast padding to wrap the two fingers together, and continue proximally up the hand, utilizing the first webspace for hand integration, up to the proximal 1/3 of the forearm. When completed, take the plaster/fiberglass, and cut a distal longitudinal slit to allow for the thumb to be excluded from splint. Once full skin protection is ensured, take premeasured, wet, stripped plaster/fiberglass, and place to the radial aspect of the forearm with the distal portion including the volar and dorsal aspect of the index and long fingers. The remaining digits should be free. Wrap plaster/fiberglass with bias/ACE from the distal IP joint proximally up the hand to the forearm. Tape to secure. Avoid wrapping too tightly. Ensure desired position and allow plaster to set.

Ulnar Gutter (Fig. 38.6)

- *Indications*—injuries for use include fourth and/or fifth metacarpal fractures and soft tissue injury.
- *Positioning*—extend wrist slightly with flexed metacarpophalangeal joint 70–90°.
- *Technique*—place 4 × 4 gauze between small and ring finger for webspace protection. Use cast padding to wrap the two fingers together, and continue proximally up the hand, utilizing the first webspace for hand integration, up to the proximal 1/3 of the forearm. Once full skin protection is ensured, take premeasured wet, stripped plaster/fiberglass, and apply to ulnar border of the hand and forearm overlapping the volar and dorsum of the small and ring fingers. Wrap plaster/fiberglass with bias/ACE from the distal IP joint proximally up the hand

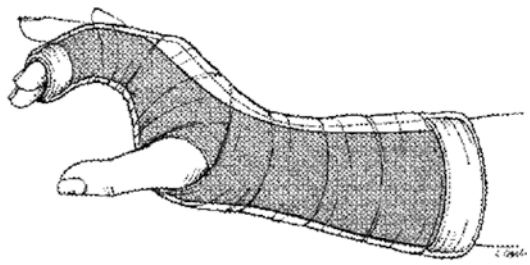

Fig. 38.5 Radial gutter splint. (Reprinted from WikEM. Retrieved from: https://www.wikem.org/wiki/Radial_gutter_splint. With permission from Creative Commons License 4.0: https://creativecommons.org/licenses/by-sa/4.0/)

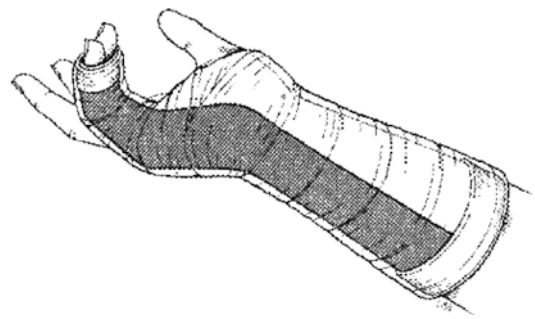

Fig. 38.6 Ulnar gutter splint. (Reprinted from WikEM. Retrieved from: https://www.wikem.org/wiki/Ulnar_gutter_splint. With permission from Creative Commons License 4.0: https://creativecommons.org/licenses/by-sa/4.0/)

to forearm. Tape to secure. Avoid wrapping too tightly. Ensure desired position and allow plaster to set.

Sugar-Tong (Fig. 38.7)

- *Indications*—injuries for use include distal radius fracture and ulna fracture, isolated or both bone fractures. It is used to prevent forearm rotation of the wrist or elbow.
- *Positioning*—flexion of the elbow at 90° and neutral position of the wrist and hand with thumb up. Ensure no extreme flexion of the wrist, as this can result in median nerve compression.
- *Technique*—place stockinette and then cast padding beginning distally at the palm of the hand, leaving the metacarpophalangeal joints free, and extend proximally to include the elbow. Ensure extra padding at bony prominence over the olecranon. Once full skin protection is ensured, take premeasured wet, stripped plaster/fiberglass, and apply one end to the volar aspect of the hand at the midpalmar crease. Bring the plaster/fiberglass around the elbow, and extend it up to the dorsum of the hand in a U shape, leaving the metacarpophalangeal joints free. This position and elimination of digits should allow for full finger motion. Wrap plaster/fiberglass with bias/ACE distally from metacarpophalangeal joints proximally to the elbow. Tape to secure. Avoid wrapping too tightly. Ensure desired position and allow plaster to set.

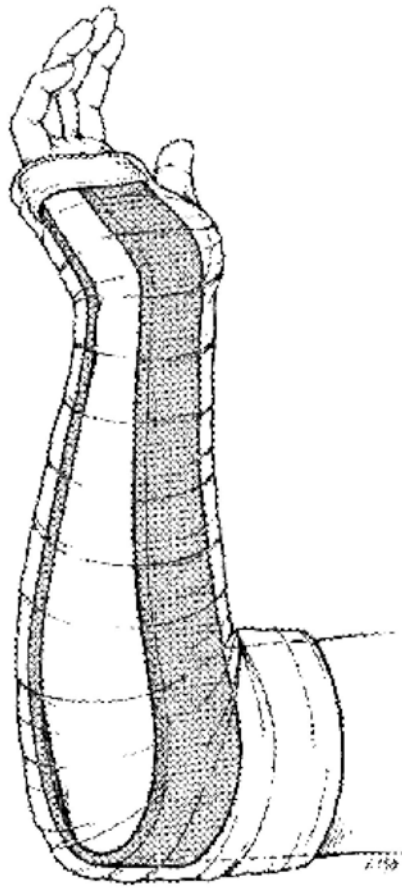

Fig. 38.7 Sugar-tong splinting. (Reprinted from WikEM. Retrieved from: https://www.wikem.org/wiki/Sugar_tong_splint. With permission from Creative Commons License 4.0: https://creativecommons.org/licenses/by-sa/4.0/)

Posterior Long Arm Splint (Fig. 38.8)

- *Indications*—injuries for use include elbow (olecranon) fractures, post-reduction of an elbow dislocation, humerus fractures, and radial head and neck fractures.
- *Positioning*—flexion of the elbow at 90° with neutral positioning of the forearm and wrist with thumb up.
- *Technique*—cut hole in stockinette for the thumb, and use cast padding to wrap from metacarpophalangeal joints to the proximal 1/3 of the humerus. Ensure extra padding over bony prominence of olecranon. Once full skin protection is ensured, take premeasured, wet, stripped plaster/fiberglass, and apply one end to the ulnar aspect of the wrist, proximally up the forearm and over the elbow to the posterior aspect of the humerus. Wrap plaster/fiberglass with bias/ACE Tape to secure. Avoid wrapping too tightly. Ensure desired position and allow plaster to set.

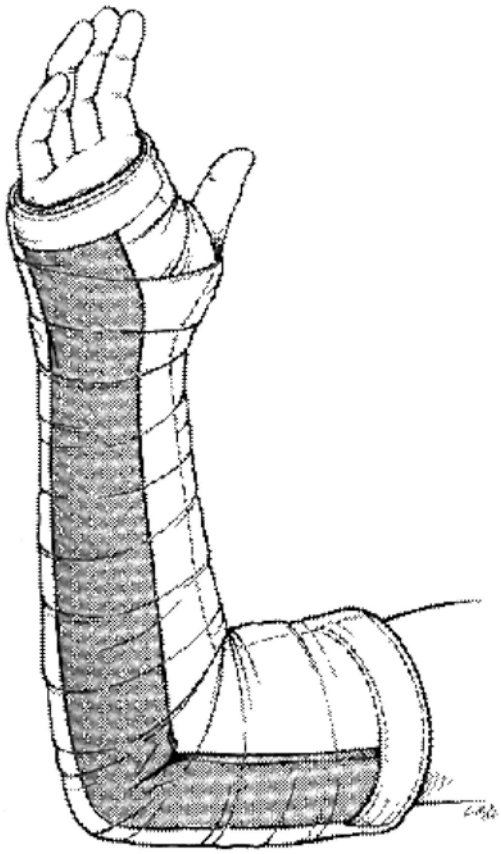

Fig. 38.8 Posterior long arm splint. (Reprinted from WikEM. Retrieved from: https://www.wikem.org/wiki/Long_arm_posterior_splint. With permission from Creative Commons License 4.0: https://creativecommons.org/licenses/by-sa/4.0/)

Coaptation Splint

- *Indications*—injury for use includes humerus shaft fractures.
- *Positioning*—elevate head of bed 70–90° to assist with fracture lengthening, with the elbow in flexion at 90°.
- *Technique*—apply stockinette, and then begin placing cast padding at the proximal forearm and move up the humerus and over the shoulder to include distal clavicle. Ensure that bony prominence over olecranon is well padded. Place one end of premeasured, wet, stripped plaster/fiberglass in the axilla, and wrap it down under the elbow in a U shape and up and over the shoulder nearing the end of plaster/fiberglass at the base of the neck. Wrapping the ends of the splint both at the axilla and over the shoulder with an abdominal pad or extra cast padding to ensure skin protection is recommended. Wrap plaster with bias/ACE. Tape to secure. Avoid wrapping too tightly. Axial traction would then be held through the elbow and a valgus mold placed on the humerus for fracture reduction. A hand placed firmly on the splint over the shoulder is helpful during the traction and mold placement, in order to keep the splint from slipping. If the plaster is not extended over the distal clavicle, immobilization of the shoulder joint is not achieved. Ensure desired position and allow plaster to set.

Common Splinting Techniques for the Lower Extremity [4–6]

Bulky Jones (Fig. 38.9a, b)

- *Indication*—injuries for use include calcaneus fractures, ankle injuries, or fractures with significant swelling.
- The actual plaster or fiberglass portion is simply a short posterior slab splint. The purpose of bulky cast padding is intended for foot/ankle fractures with notable swelling potential and to ensure appropriate padding to heel with calcaneus fractures.
- *Position*—for placement of splint, allow flexion of the knee to enable relaxation of gastrocnemius and neutral position (90°) of the ankle. With some fracture patterns and those with operative needs, swelling and pain may be such that a fully neutral position may not be attained and slight equinus is accepted.
- *Technique*—hold the leg with knee in flexion to allow for gastrocnemius to relax and ankle in neutral position (90°), apply stockinette, and then use cast padding to wrap from metatarsal heads proximally to tibial tuberosity. Ensure attention to padding over bony prominences of medial and lateral ankle and heel. The bulky Jones dressing is added by fanning out one complete roll of cast padding and

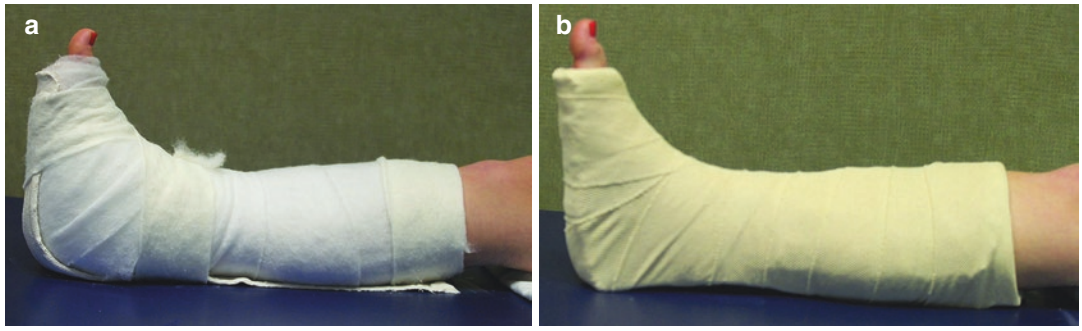

Fig. 38.9 (**a**, **b**) Bulky Jones splint

Fig. 38.10 Short posterior splint with sugar-tong (stirrup)

placing this over the heel and both the medial and lateral malleoli. A short posterior splint will then be added as described above, terminating at the proximal tibia posteriorly just distal to the popliteal fossa to allow full knee motion. Wrap plaster/fiberglass with bias/ACE. Tape to secure. Avoid wrapping too tightly. Ensure desired position and allow plaster to set.

Short Posterior Splint with Sugar-Tong (Stirrup) (Fig. 38.10)

- *Indication*—injuries for use include stabilization of severe (grade 2 and/or 3) ankle sprains, metatarsal and midfoot fractures, ankle fractures, ankle dislocations, and distal tibia fractures. The sugar-tong, or stirrup component, increases the stability of splint and prevents inversion, eversion, and plantar flexion of the ankle.
- *Positioning*—for placement of splint, allow flexion of the knee to enable relaxation of the gastrocnemius, and hold the ankle in neutral position (90°). This is very important with long-term splints in order to prevent an equinus ankle contracture.
- *Technique*—with the leg held in position as described above, apply stockinette, and then use cast padding to wrap from toes proximally to tibial tuberosity. Ensure attention to padding over bony prominences of the medial and lateral ankle and heel. Place premeasured, wet, stripped plaster/fiberglass applying posterior slab from metatarsal heads just distal to popliteal fossa (allows unobstructed motion of knee). The sugar-tong (stirrup) piece is then added to the medial and lateral aspects of the calf wrapping under the plantar aspect of the foot, terminating just below the fibular head to avoid compression of peroneal nerve. Wrap plaster/fiberglass with bias/ACE. Tape to secure. Avoid wrapping too tightly. Ensure the ankle remains at 90° and allow plaster to set.

Long Leg Splint (Fig. 38.11)

- *Indication*—injures for use include proximal or mid-shaft tibia fractures, knee injuries (post-reduction of dislocations, ligamentous injury), distal femur fractures, and patella fractures.
- *Position*—10° of knee flexion and neutral position of the ankle at 90°.

Fig. 38.11 Long leg splint. (Reprinted from WikEM. Retrieved from: https://wikem.org/wiki/Long_leg_posterior_splint.With permission from Creative Commons License 4.0: https://creativecommons.org/licenses/by-sa/4.0/)

- *Technique*—with provider holding gentle axial traction at the ankle with leg elevated, and if available, a second assistant supporting leg at the thigh with support under fracture site, apply stockinette, and then place cast padding from toes to proximal thigh just distal to gluteal crease. Ensure that proper bony prominences of ankle and heel are well padded. Place posterior portion of premeasured, wet, stripped plaster/fiberglass from metatarsal head to proximal posterior thigh. If ankle immobilization is required for fracture pattern (mid-shaft tibia fracture), add a long sugar-tong (stirrup) as previously described, and extend the medial and lateral portion proximally to the distal femur. This ensures immobilization of both ankle and knee joints. With proximal tibia or distal femur fractures, you may opt to place short side slabs of plaster/fiberglass to immobilize the knee when the ankle is not necessary. Wrap wet plaster/fiberglass with bias/ACE. Tape to secure. Avoid wrapping too tightly. Ensure desired position and allow to harden.

Complications from Splinting or Casting [9]

Although splint placement in educated and practiced hands may be seen as a benign procedure, it can cause complications. Attention to detail during placement and careful notation of the finished product is vital to ensure safety.

Burns [3, 8]

Both plaster and fiberglass splint materials harden via a chemical (exothermic) reaction that produces heat. The strength provided by the splint is directly correlated to the layers of material used. Therefore, the more layers used, the more heat is produced at an increased risk of burning a patient's skin. If hot water is used for dipping, more heat is generated leading to an increased risk of burns. Adequate skin protection with cast padding in combination with room temperature water use is imperative in order to avoid thermal burns. Careful attention must be directed to patient concerns and complaints of significant and painful warmth after splint is completed. Have a low threshold for removal and revision if no relief is achieved.

Compartment Syndrome

A compartment syndrome is a condition in which increased pressure within a confined space compromises the contents of that space. Although most common in the lower extremities and with circumferential casting, it must be respected that splinting can cause some degree of extremity compression, resulting in further limitation of the available space. Frequent neurovascular exams must be performed on any patient splinted.

Contractures

In the acute setting, most splints are placed with the anticipation of early intervention or fixation. However, if long-term splinting is anticipated, close attention must be placed to the unaffected joints surrounding the fracture site. Any unnecessary joints must be left free to allow unrestricted range of motion. Otherwise, contractures may develop contributing to further immobility and functional deficit.

Skin Compromise

A thorough evaluation of the patient's skin condition prior to splint placement is included in the initial exam. Risk of acute skin compromise may occur to areas of pressure whether from fracture pattern or splint material. Adequate protection of bony prominences will decompress and prevent further decline of tenuous soft tissues. Frequent monitoring or scheduled skin checks are encouraged for those deemed at risk. If in doubt of padding sufficiency, add more.

Nerve Compression

Final position of the injured extremity when splinted is essential. Specific angles are provided above in application techniques to assist with deterrence of nerve compression secondary to prolonged positioning and/or pressure. For example, if a wrist is hyperflexed and remains splinted for a prolonged course, compression of the median nerve could occur and become a complication not from injury but from splint positioning. Similarly, a hyperflexed elbow with long arm splints could lead to compression and symptoms of the ulnar nerve. Special attention must be given to final positioning of splint in order to avoid splint-related nerve symptoms.

Orthopedic injuries are very common in the trauma population, and they will require appropriate immobilization. A thorough physical examination, review of radiographs, realignment of fracture if displaced, and correct choice of splint based upon injury will be required of the treating orthopedic team. Given the various types of immobilization, practice really does make perfect. Special attention must be given after completion to ensure skin protection and correct position in order to avoid complications.

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39 Advanced Fracture Management Principles of Procedures for Stabilization

C. Amanda Cullipher and Jason Halvorson

Introduction

Polytrauma patient management includes prompt identification and treatment of fractures and dislocations to stabilize the extremity or joint and reduce further damage to surrounding tissue and structures. Standard treatment includes reduction techniques (both open and closed) with procedures for temporary stabilization until definitive operative fixation can occur. The goal of this chapter is to introduce skeletal traction and external fixation as two methods to achieve closed reduction of fractures and dislocations in the unstable trauma patient. The basic principles and techniques of each will be discussed, as well as considerations, contraindications, and complications.

Fracture Management: Basic Principles

While no two fractures are identical, the same general principles apply when managing all types of fractures. Once a fracture is identified, it is classified as nondisplaced or displaced. Nondisplaced fractures refer to fractures where the bone is anatomically aligned and maintains alignment without undergoing a formal reduction or manipulation. These types of fractures heal well with immobilization in a splint, cast, or brace. Displaced fractures are characterized by fracture patterns where the bone fragments are not in anatomic position and require reduction maneuvers to achieve improved alignment and reduce further injury to surrounding tissues. Fracture is then further identified by type of fracture pattern, such as compression, comminuted, oblique, transverse, spiral, or segmental.

Reduction can be achieved by several methods, and the method utilized is dependent on several factors. These factors include the type and severity of the fracture, underlying medical comorbidities, and any other traumatic or associated injuries. Noninvasive techniques of fracture manipulation are frequently used and include splinting, casting, or bracing. Other nonoperative and minimally invasive methods of reduction include skin or skeletal traction, with more invasive reduction techniques including both external and internal fixation. This chapter will give an overview of skin traction but will focus on skeletal traction and external fixation, both of which are commonly utilized in the acute care setting.

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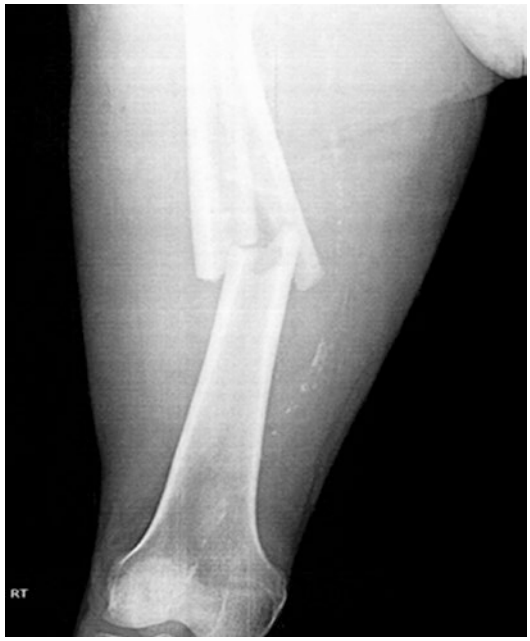

Fig. 39.1 Displaced femoral shaft fracture

Traction

When a bone is fractured or a joint is dislocated, the surrounding muscles may spasm and contract, putting more tension on the proximal and distal ends of the fracture. This can cause further displacement of the fracture, resulting in limb shortening, damage to surrounding tissues, and internal or external rotation of the limb below the level of fracture. To mitigate those issues, traction can be utilized to restore adequate limb length and provide gross fracture alignment. This technique is primarily used for stabilizing long bone fractures, such as femoral shaft (Fig. 39.1), proximal femur and hip fractures, or pelvic and acetabular fractures (Fig. 39.2).

Traction by definition creates an opposing longitudinal or axial force that is applied to the affected extremity to counteract (pull against) the muscle contraction or spasm that is causing the displacement of the fracture fragments. This technique counteracts these displacing forces and aligns the fracture and provides stabilization and immobilization until the fracture is amenable to definitive fixation.

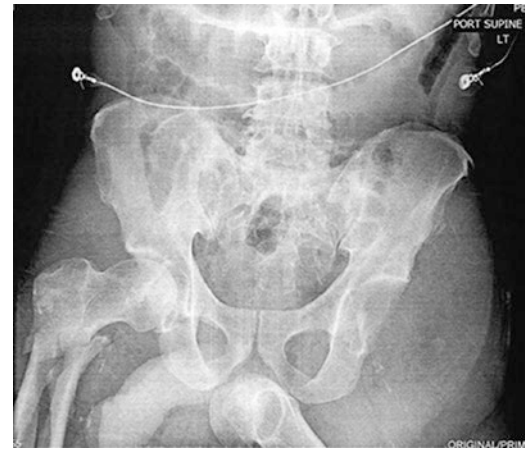

Fig. 39.2 Hip dislocation with contralateral comminuted proximal femur fracture

Skin and Skeletal Traction

Skin traction, also known as bucks traction, is a temporary, noninvasive method of stabilizing a limb until skeletal traction or immediate surgical intervention is available. Skin traction is accomplished by using adhesive strips or a "bucks" boot to provide traction. The bucks boot is a prefabricated boot that uses adhesive strips to wrap firmly around the patient's foot and lower leg so that traction can be applied. The advantage to skin traction is the immediate availability of providing traction, but there are several disadvantages and complications that can occur. The main disadvantages to skin traction include skin breakdown, limited time skin traction can be used (due to concern for skin breakdown), and the limited use of weight applied (no more than 10 lbs). Skin breakdown, especially in elderly population or those with current skin issues, can cause prolonged hospitalization due to increased risk of infection. The main complications other than skin breakdown include the high likelihood of the patient sliding down in bed (resulting in weight on floor) or the boot sliding off patient, both of which result in the traction not providing desired pull and stabilization [1].

Skeletal traction is a more invasive method of reduction that involves the insertion of a

Kirschner wire (K-wire) or Steinmann pin through bone below the level of the fracture. K-wires are smaller in diameter and require a tension bow with traction setup, while Steinmann pins are larger in diameter and a non-tension bow is used. One advantage of using skeletal traction over less invasive methods of traction is that it provides a more direct force to the fracture fragments allowing for a better reduction [2]. Skeletal traction can be performed at the bedside with local anesthetic with relative ease. Several skeletal sites are available for this method of traction and include the skull (for unstable cervical spine injuries), distal femur, proximal tibia, distal tibia, calcaneus, and olecranon. For the purpose of this chapter, temporary skeletal traction of the distal femur and proximal tibia will be described in greater detail.

Skeletal Traction: End of Bed Traction Versus Balanced Traction

Once the need for skeletal traction is determined, the type of traction also needs to be decided. EOB traction is used primarily for long bone fractures, such as femur and tibial fractures, while balanced traction is generally used for pelvic and/or acetabular fractures. End of bed (EOB) traction is the most common type of traction used, with the weight pulling directly away from the fracture toward the end of the bed. The goal of this type of traction is to attempt to restore length and a more anatomic position by pulling directly on the extremity to achieve better alignment. Balanced traction uses EOB traction and also includes a system of pulleys, ropes, and weights that provides a counterbalance to the entire leg while providing traction. The purpose of balanced traction is to suspend the extremity in a slightly flexed position that relaxes the surrounding muscles and disperses the traction through the entire leg, so the force of traction is not directly pulling on one specific body part.

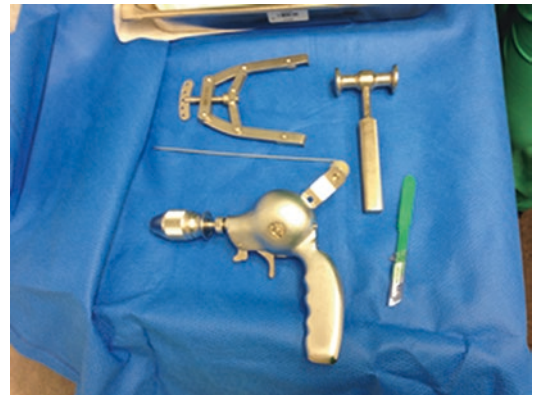

Fig. 39.3 Kirschner wire tray (clockwise from left: tension bow, hammer, scalpel, drill, K-wire)

Preparation

Materials and Supplies

1. K-wire (Fig. 39.3) or Steinmann pin tray (Fig. 39.4)—contents are facility specific but should include pins or wires, drill, hammer, bow, and pliers/wire cutters.
2. Sterile gloves.
3. Betadine or ChloraPrep.
4. Scalpel.
5. Sterile towels.
6. Sterile gloves.
7. 4 × 4 gauze.
8. 1% lidocaine.
9. 10 mL syringe and 18 g or 20 g needle for injection (may need spinal needle for obese patients).
10. Xeroform/ABD pads.
11. Caps or protective covering for end of pins.
12. Skin marker.
13. Traction frame for bed.
14. Traction weights/ropes.

Skeletal Traction: Distal Femur

Distal femoral traction is most often the traction site of choice for proximal femur fracture, acetabulum fracture dislocations, and complex

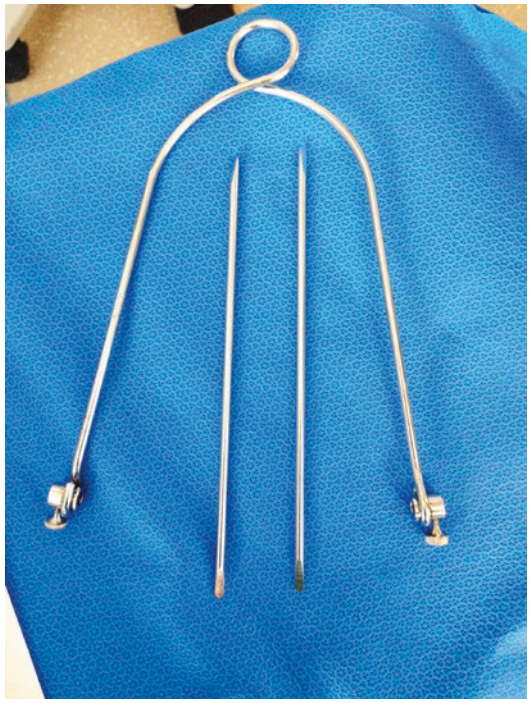

Fig. 39.4 Steinmann pin with non-tension bow

pelvic ring injuries including sacroiliac joint fracture dislocations. In patients with diaphyseal fractures of the femur and ipsilateral injury to the knee or proximal tibia, distal femoral traction is utilized as well since proximal tibial traction is contraindicated with these associated injuries [2].

General Considerations

- Obtain radiograph of the *entire femur* prior to placement to confirm traction pin is not inserted through a fracture or bony abnormality. Ensure fracture line does not extend down to area of insertion or intra-articularly.
- Adequately identify landmarks, and always insert pin from medial to lateral to avoid injury to surrounding neurovascular structures [2]. If inserted too distal, there is an increased risk of entering the knee joint at the intercondylar notch. Conversely, if inserted too proximal, there is a risk of damaging the neurovascular structures, such as the femoral artery [3].

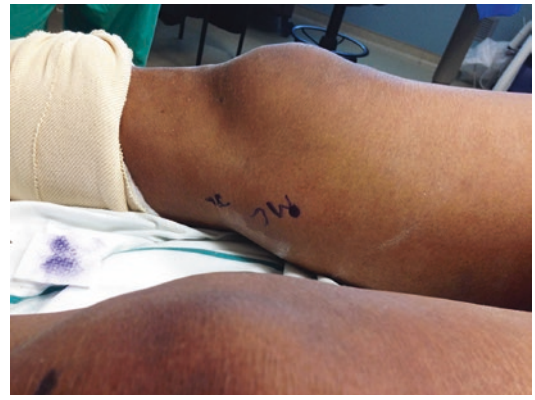

Fig. 39.5 Skin markings indicating insertion point of K-wire

- Traction pin should be inserted parallel to the knee joint [3].
- It is important to have someone to help hold the patient's extremity in neutral alignment to ensure proper placement of traction pin.

Technique for Pin Insertion

1. With patient supine, position the affected extremity in neutral alignment, with knee slightly flexed 30° over a bump and with the toes and patella pointing toward ceiling. Be aware that some patients will prefer to keep their leg straight, but slight flexion helps move important medial anatomy down and away from pin exit site, which can decrease chance of inadvertently hitting nerve or vascular structures.
2. Identify the superior margin of the patella, and palpate along the medial aspect of the distal femoral condyle. The insertion point will be approximately 2 cm (2 fingerbreadths) proximal to the superior margin of the patella and 2 cm medial, just proximal to the medial epicondyle or adductor tubercle (Fig. 39.5) [3]. Note that in an obese patient, these measurements will need to be adjusted to ensure that insertion point is in the middle of the bone.
3. Once the bony landmarks are identified, mark your planned insertion and exit points

with a skin marker, and begin preparing your field and the extremity. Often, patients present with a temporary traction splint from the emergency department. Leave the extremity in traction during the procedure, but ensure that the sides are cut back or adjusted to allow adequate access.

4. Cleanse area of injection sites prior to administration of local. Administer a local bolus of anesthetic to both marked areas of the entrance (Fig. 39.6) and exit (Fig. 39.7) points of the traction pin. On the insertion side, insert needle down to bone, and then inject lidocaine. The exit point will be on the lateral side of the distal femur and should be directly across from the insertion site. Use approximately 5 mL lidocaine per side.
5. Cleanse area with Betadine or ChloraPrep solution.
6. Wash hands, and apply sterile gloves. *Procedure is now sterile until dressings are applied.*
7. Apply surrounding portions of prepped extremity with sterile towels, leaving only the immediate area exposed (Fig. 39.8) [4].
8. Attach battery to drill and check battery is charged. Attach drill head component if separate from drill body. Pull on battery and drill head to ensure correctly attached.
9. Select the appropriate K-wire pin size (usually 2 mm) or Steinmann pin (usually 4 mm), and place into drill [5]. Depending on drill

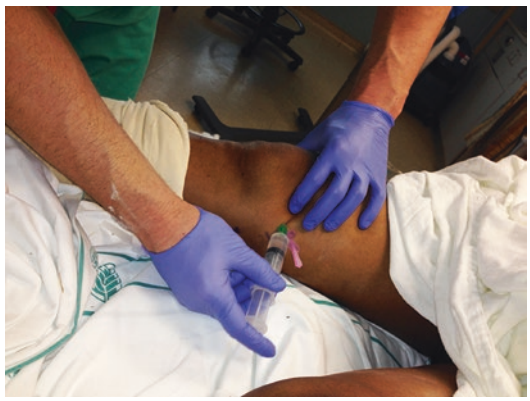

Fig. 39.6 Injection of lidocaine into insertion point of K-wire, medial aspect of distal femur

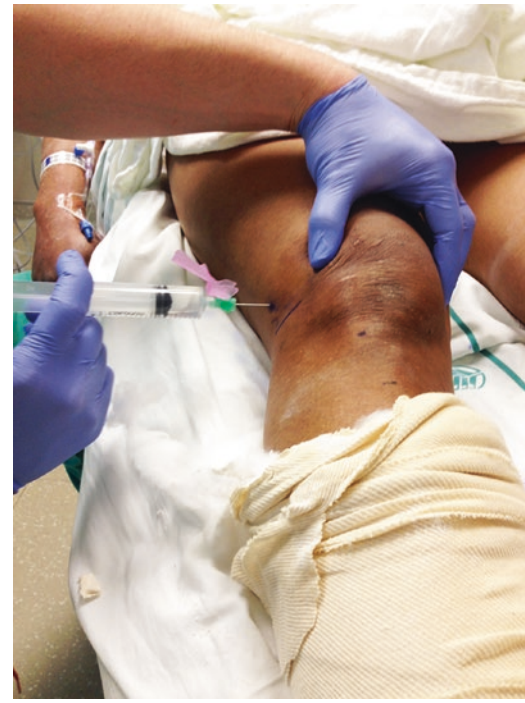

Fig. 39.7 Injection of lidocaine into the projected exit point of the K-wire, lateral aspect of distal femur

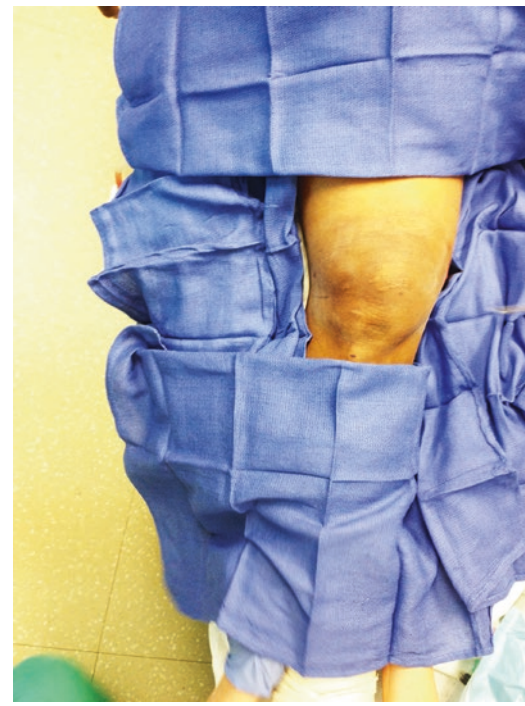

Fig. 39.8 Extremity prepped in sterile fashion

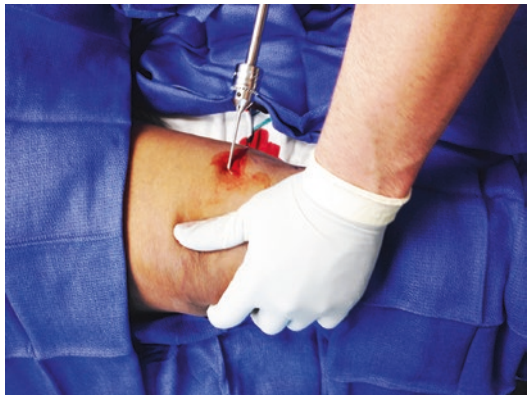

Fig. 39.9 K-wire advancing through medial cortex of the distal femur

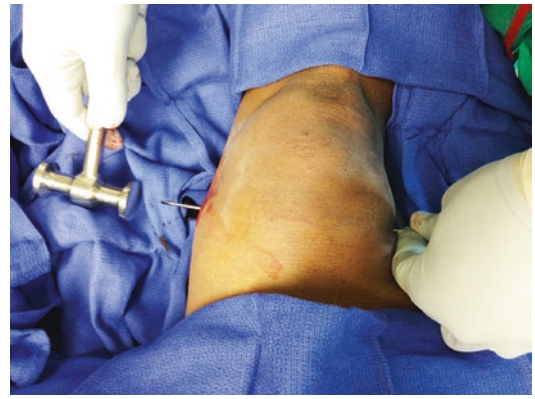

Fig. 39.10 Gently hammering K-wire

used, you may need to tighten drill head down to adequately grasp pin. Ensure pin is seated in the center of the drill before tightening completely. (Some facilities only offer one size in traction pin tray, but other sizes should be available in sterile packages, which usually can be obtained from the operating room.)

10. Make a small stab incision using scalpel at insertion site along the medial aspect of the leg.
11. Insert K-wire into incision. Make sure wire is centered on bone. You may need to use the wire (by walking up and down the bone) to identify the anterior and posterior cortices of the bone to locate the center. Once appropriate position is confirmed, begin advancing using the drill with *forward* trigger only (Fig. 39.9). Be sure that hand and drill are parallel to the bed to ensure pin is advancing in a straight line. If your hand is skewed in any plane, the pin will not go through the center of the bone or may go through in an oblique angle. Once the pin passes through the medial cortex, it will advance easily until it reaches the lateral cortex. Be careful not to press too hard or fast once the lateral cortex is breached. As soon as the lateral cortex is breached or the tip of the pin tents the skin, *stop* drilling and make a small stab incision to expose the end of the pin.
12. Remove the pin from the drill. Using the hammer, lightly tap the medial end of the pin until there are equal parts of the pin exposed on both sides (Fig. 39.10). Do not hammer the pin through the bone; this could cause fracture around the pin site ([6], p. 122).
13. Attach bow to the traction pin, and give it a gentle tug to make sure it is secure before the weights are attached.
14. Cut the exposed portion of the traction pin with wire cutters/pliers. Bend or cap ends with protective covering to prevent injury from the sharp ends.
15. Apply Xeroform to skin around pin sites. Fold ABDs in half and make small cut to place around pins.
16. Wrap the towels around the bow to protect the soft tissues and bony prominences from pressure once weights are attached *Never* leave bow lying directly on the leg, as this will cause skin breakdown and necrosis.
17. For an average-sized adult, the lower extremity can tolerate approximately 20% of the individuals' body weight, which is usually 20–25 pounds of countertraction. This is applied using the traction frame with a trapeze and pulley apparatus attached to the patient's bed [2].

Skeletal Traction: Proximal Tibia

Proximal tibial traction is most often used in patients with diaphyseal fractures of the femur that may extend distally or in very obese patients

where femoral traction pins are not available due to body habitus. This method is contraindicated in patients with associated fractures of the proximal tibia or ligamentous injuries to the knee. In addition, it should never be used in children as it could damage physeal bone, causing asymmetric closure of growth plates, resulting in deformity to the extremity [3].

General Considerations

- Obtain radiograph of the *knee and entire lower leg* prior to procedure to confirm that traction pin is not inserted through a fracture or bony abnormality.
- Adequately identify landmarks for pin insertion. Always insert traction pin from lateral to medial to avoid injury to the common peroneal nerve [3].
- It is important to have someone help hold the patient's extremity in neutral alignment to ensure accurate placement of traction pin.

Technique

1. With patient supine, position the affected extremity in neutral alignment, with the toes and patella pointing toward ceiling (Fig. 39.11).
2. Identify the patella, patellar tendon, tibial tuberosity (Fig. 39.12), and the fibular head, where the common peroneal nerve is located posteriorly; these will serve as the landmarks for proper pin insertion [7]. If needed, use a skin marker to identify the landmarks.
3. Measure 2.5 cm distal to the level of the tibial tuberosity (Fig. 39.13) and 2.5 cm posterior to the tibial tuberosity (Fig. 39.14) (aka 1–2 fingerbreadths) [3]. This will be the insertion site of the traction pin.
4. Once the bony landmarks are identified, mark your planned insertion and exit points with a skin marker, and begin preparing your field and the extremity. Often, patients present with a temporary traction splint from the emergency department. Leave the extremity in traction during the procedure, but ensure that the sides are cut back or adjusted to allow adequate access (Fig. 39.11).
5. Cleanse area of injection sites prior to administration of local. Administer a local bolus of anesthetic to both marked areas of the entrance and exit points of the traction pin. On the insertion side, insert needle down to bone, then inject lidocaine. The exit point will be on the medial side of the tibia, and should be directly across from the insertion site. Use approximately 5 mL Lidocaine per side.
6. Cleanse area with Betadine or ChloraPrep solution.

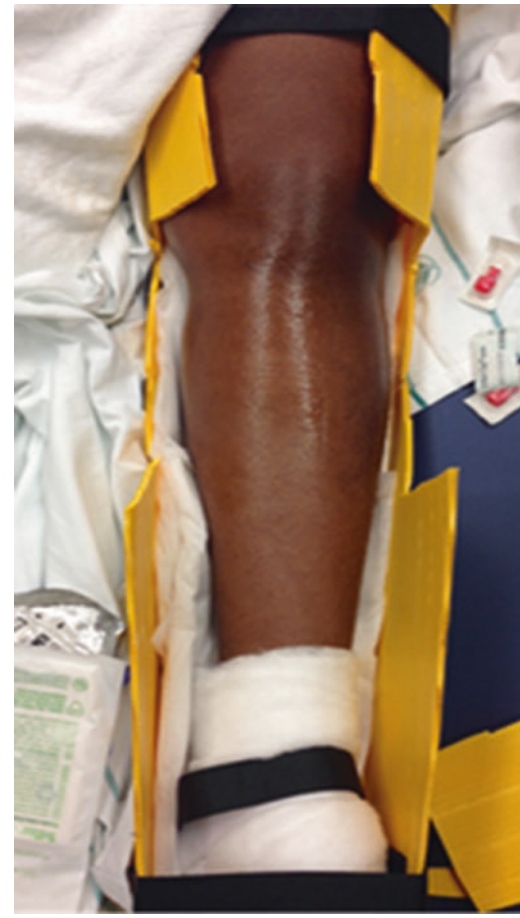

Fig. 39.11 Trauma patient with lower extremity in temporary traction splint

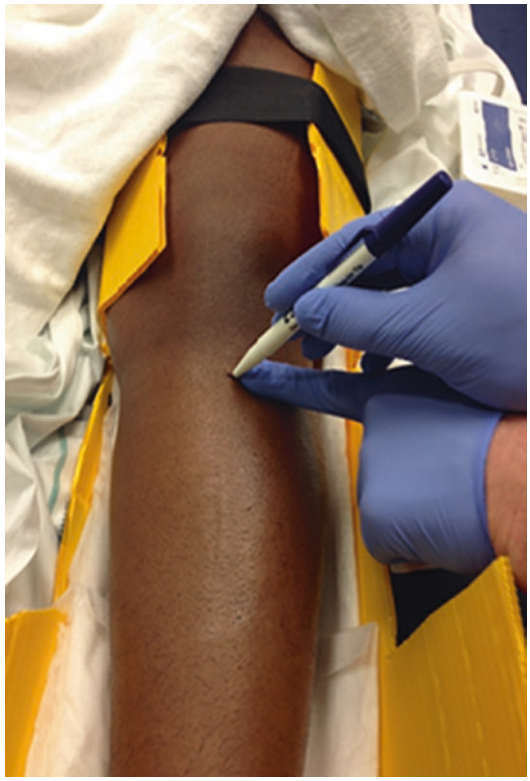

Fig. 39.12 Tibial tuberosity

7. Wash hands, and apply sterile gloves. *Procedure is now sterile until dressings are applied.*
8. Apply surrounding portions of prepped extremity with sterile towels, leaving only the immediate area exposed (see prior Fig. 39.8 as reference) [4].
9. Attach battery to drill and check battery is charged. Attach drill head component if separate from drill body. Pull on battery and drill head to ensure correctly attached.
10. Select the appropriate K-wire pin size (usually 2 mm) or Steinmann pin (usually 4 mm) and place into drill [5]. Depending on drill used, you may need to tighten drill head down to adequately grasp pin. Ensure pin is seated in the center of the drill before tightening completely. (Some facilities only offer one size in traction pin tray, but other sizes should be available in sterile packages, usually can be obtained from the Operating Room).

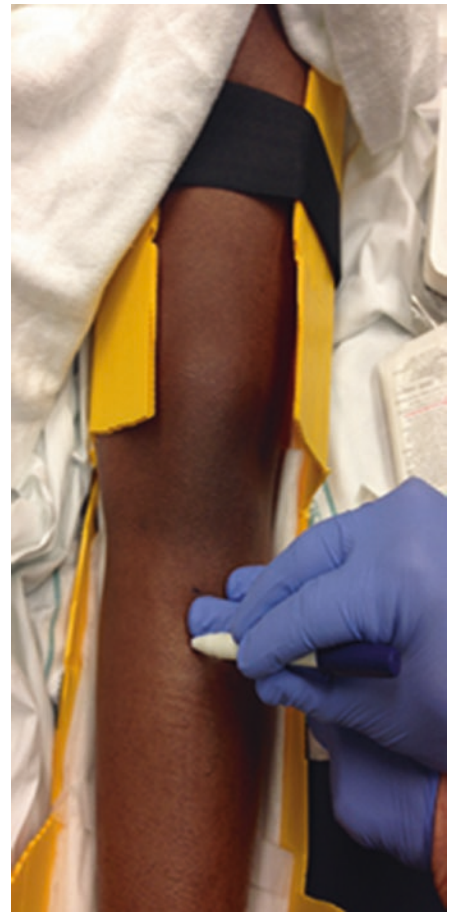

Fig. 39.13 2.5 cm distal to tibial tuberosity

11. Make a small stab incision using scalpel at insertion site along the medial aspect of the leg.
12. Insert K-wire into incision. Make sure wire is centered on bone. You may need to use the wire (by walking up and down the bone) to identify the anterior and posterior cortices of the bone to locate center. Once appropriate position is confirmed, begin advancing using the drill with *forward* trigger only (Fig. 39.15). Be sure that hand and drill are parallel to the bed to ensure pin is advancing in a straight line. If your hand is skewed in any plane, the pin will not go through the center of the bone or may go through in an oblique angle. Once the pin passes through the lateral cortex, it will advance easily until it reaches the medial cortex. Be careful not to

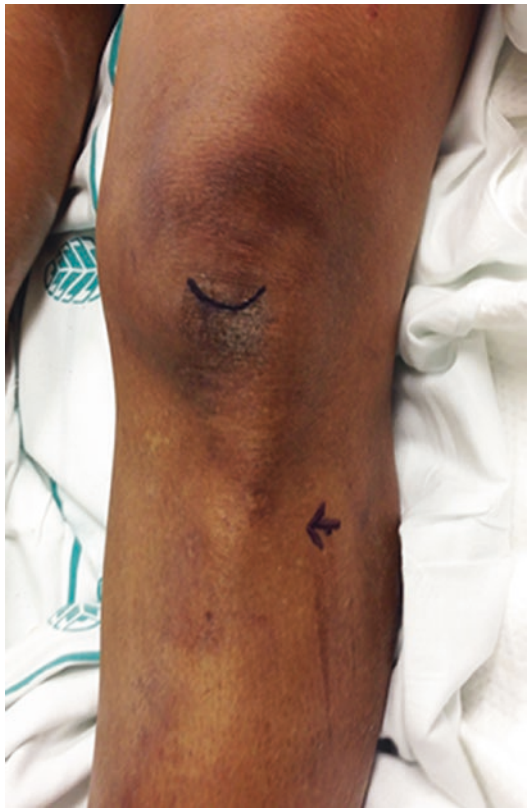

Fig. 39.14 2.5 cm posterior to tibial tuberosity

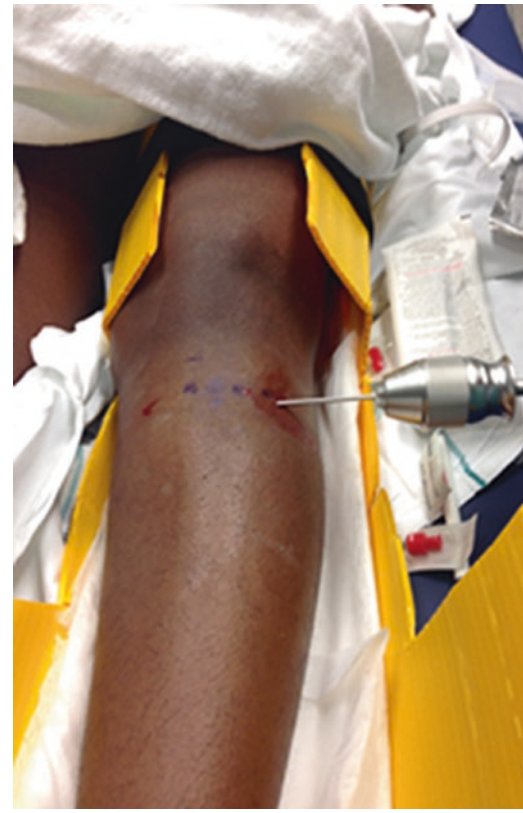

Fig. 39.15 Insertion of proximal tibia tissues traction pin—lateral to medial

press to hard or fast once the lateral cortex is breached. As soon as the lateral cortex is breached or the tip of the pin tents the skin, *stop* drilling and make a small stab incision to expose the end of the pin. (Fig. 39.16).

13. Remove the drill. Using the hammer, lightly tap the lateral end of the pin until there are equal parts of the pin exposed on both sides (Fig. 39.17). Do not hammer pin through the bone as this could cause fracture at the pin site ([5], p. 122).
14. Attach bow to the traction pin and give it a gentle tug to make sure it is secure before the weights are attached. (Fig. 39.18)
15. Cut the exposed portion of the traction pin with wire cutters/pliers. Bend or cap ends with protective covering to prevent injury from the sharp ends. (Fig. 39.19).
16. Apply Xeroform to skin around pin sites. Fold ABDs in half and make small cut to place around pins.
17. Wrap the towels around the bow to protect the soft tissues and bony prominences from pressure once weights are attached. *Never* leave bow lying directly on the leg, as this will cause skin breakdown and necrosis.
18. For an average-sized adult, the lower extremity can tolerate approximately 20% of the individuals' body weight, which is usually 20–25 pounds of countertraction. This is applied using the traction frame with a trapeze and pulley apparatus attached to the patient's bed [2].

External Fixators: Principles

The primary mechanism of injury for trauma patients in the acute care setting who sustain polytrauma injuries is usually the result of high-energy traumas such as motor vehicle collisions

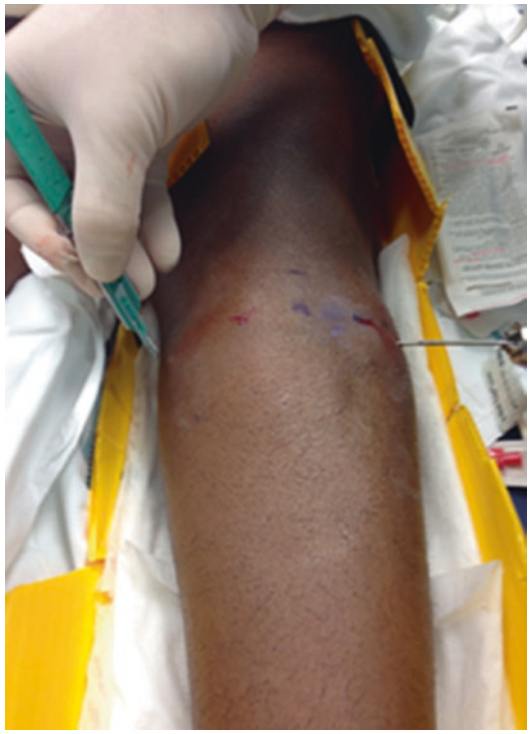

Fig. 39.16 Traction pin tenting medial soft tissues

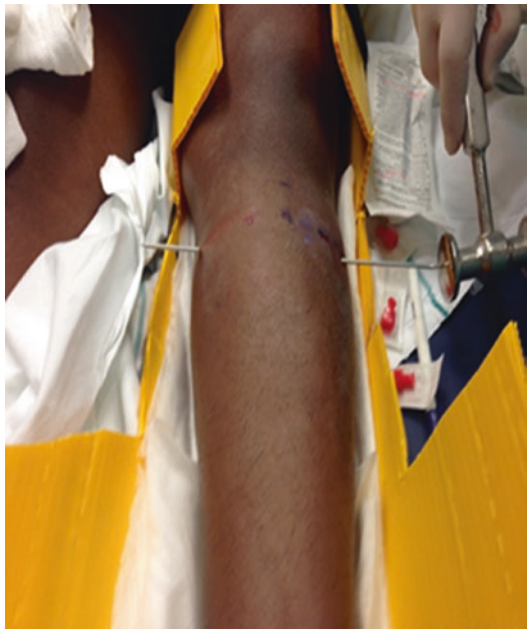

Fig. 39.17 Hammering of K-wire pin once lateral end exposed

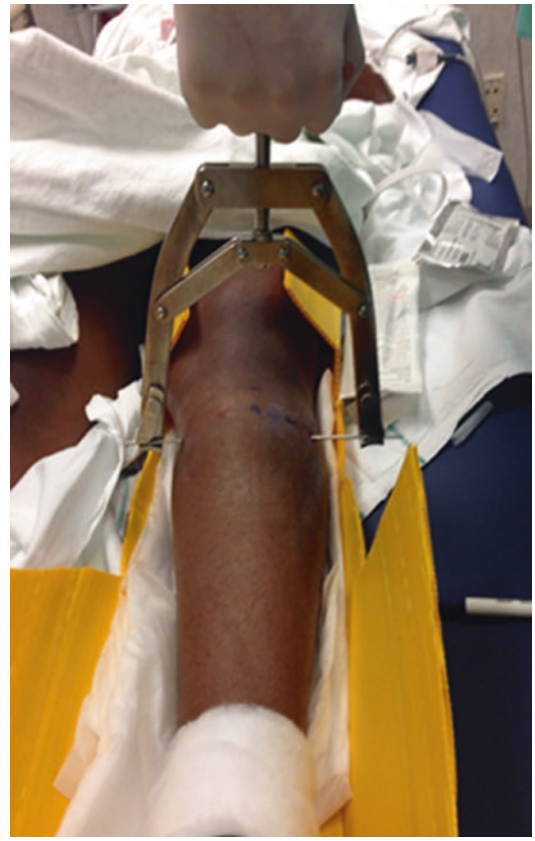

Fig. 39.18 Gentle tug of bow

or falls from a height (>10 ft). These injuries and fractures may be comminuted and displaced and have associated soft tissue, nerve, or vascular injuries that require timely stabilization in the operating room (Fig. 39.20). In the event that the patient cannot undergo definitive internal fixation, whether it be due to soft tissue injury/edema or concomitant comorbidities, an external fixator has proven to be an appropriate alternative.

An external fixator is essentially a scaffold utilizing transosseous pins/wires that stabilizes and aligns fractures using external pins/wires, bars/rods, rings and clamps, or any combination of these fixation devices. These devices are used to treat fractures in a variety of ways, with the primary goal being to restore anatomic length, alignment, and rotation. Acutely, external fixators are used to temporarily or provisionally stabilize fractures until the patient's physiologic state or soft tissues surrounding the fracture are amenable to

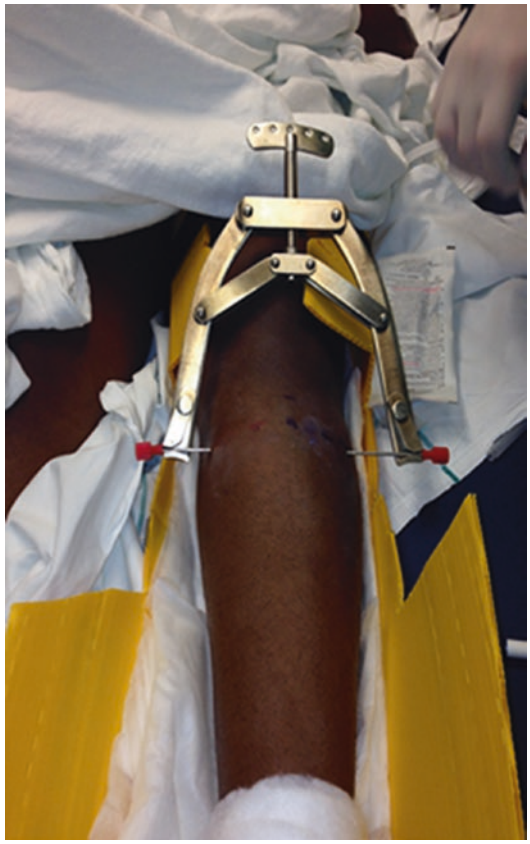

Fig. 39.19 Bow attached to K-wire with protective caps in place

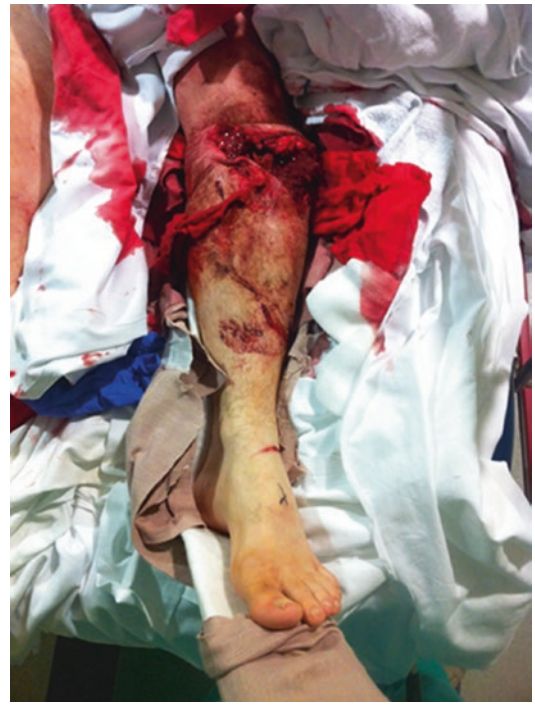

Fig. 39.20 Lower leg with fracture and overlying soft tissue injury

internal fixation. Extensive swelling, fracture blisters, and instability are all reasons to consider external fixation as a temporary treatment until definitive treatment can be performed. However, in individuals with multiple comorbidities that from a medical or trauma standpoint are unable to undergo operative fixation, external fixators can function as definitive treatment (Figs. 39.21 and 39.22). Also, fractures that are unable to achieve adequate reduction with casting or bracing may also be treated with an external fixation system.

External Fixators: Indications

While internal fixation is the ultimate goal when discussing operative fixation for the majority of fractures, it is often not the optimal choice as the initial treatment plan. As previously mentioned, in the unstable polytrauma patient, definitive fracture management is often delayed and requires staged fixation until adequate resuscitation and hemodynamic stability have been achieved, especially in the setting of traumatic brain or chest injury. In these instances, the approach of damage control orthopedics (DCO) is put to use [8]. General trauma and orthopedic surgeons have adapted the basic concepts of the damage control method, which was initially utilized by the US Navy, and applied it as an algorithm used to manage patients in the acute care setting. DCO involves the initial stabilization of "major orthopedic injuries to stop the cycle of ongoing musculoskeletal injury and to control hemorrhage" primarily with the use of external fixation ([8], p. 543). External fixators are particularly appealing for use in polytrauma patients with orthopedic injuries requiring rapid stabilization as the application of this device is minimally invasive, can be applied rapidly (often in the intensive care unit in the severely injured patient), and results in minimal blood loss [9].

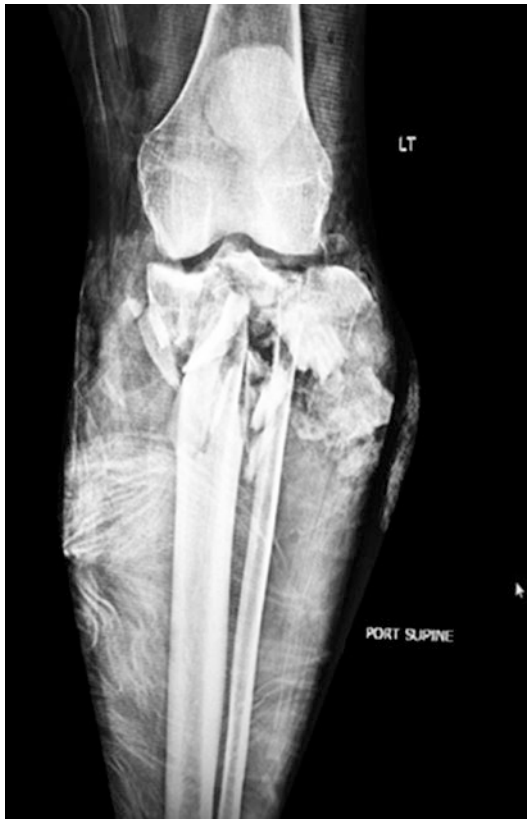

Fig. 39.21 Radiograph of severely comminuted proximal tibia and fibula fracture

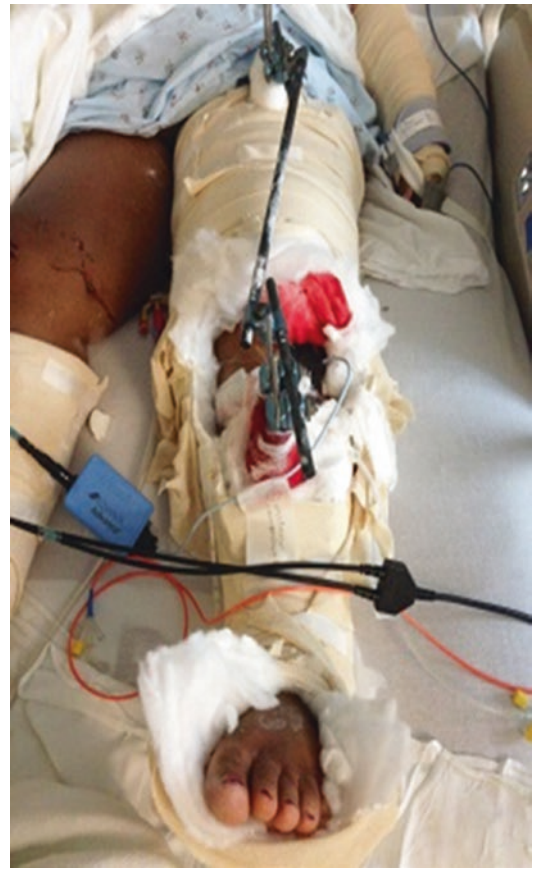

Fig. 39.22 Proximal tibia fracture treated definitively in an external fixator due to comminution and severe soft tissue injury

When indicated, external fixators can be used to treat essentially every type of fracture. The most common fracture patterns this device is used on include intra-articular fractures of the distal and proximal tibia, severely comminuted long bone fractures, unstable knee dislocations, intra-articular distal femur fractures, unstable pelvic ring injuries, and complex intra-articular fractures involving the wrist and elbow.

External fixators are also commonly used for fractures with associated soft tissue injuries, such as open fractures with complex or contaminated wounds, and for closed fractures with significant soft tissue swelling, fracture blisters, or surrounding tissue compromise. The zone of injury not only pertains to the fracture itself but also to the surrounding tissues, which must be included in the decision-making process when determining the appropriate course of treatment. Open fractures are inherently contaminated, putting the patient at an increased risk of developing a deeper soft tissue and/or bony infection [2]. In open fractures with severe soft tissue injury or contamination (Figs. 39.23 and 39.24), initial treatment with internal fixation may not be the optimal choice for the patient. The advantage of using external fixators in fractures with associated open wounds is that the fracture can be manipulated and stabilized away from the actual site of injury, minimizing further contamination and trauma to the tissues (Fig. 39.25) [10, 11]. The device also allows the provider and nursing staff easier access to the wounds for assessment and dressing changes.

The orthopedic trauma patients' journey does not end once they are downgraded in acuity from the acute care setting. Often, in patients who

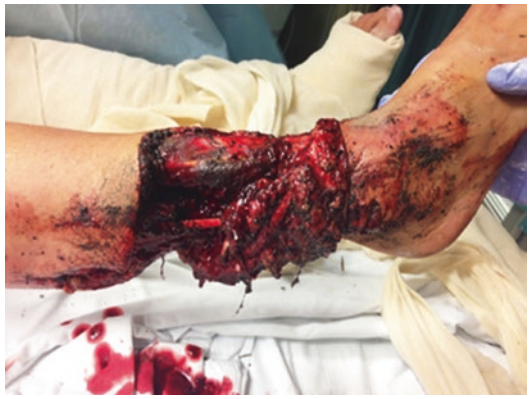

Fig. 39.23 Patient with a severe soft tissue injury with gross contamination

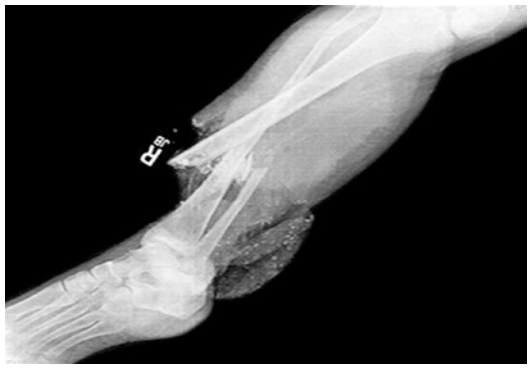

Fig. 39.24 Initial radiographs showing displaced diaphyseal tibia and fibula fractures

sustained an injury that required complex limb salvage, reconstruction is needed to correct the resultant deformity. External fixators can also be utilized to improve angular and rotational deformities associated with fracture malunion and substantial limb length discrepancies that result in cases with significant bone loss (Figs. 39.26 and 39.27; Table 39.1) [9].

External Fixators: Components and Mechanics

External fixators can be configured in a wide variety of ways to stabilize the fracture while accommodating the patient's associated soft

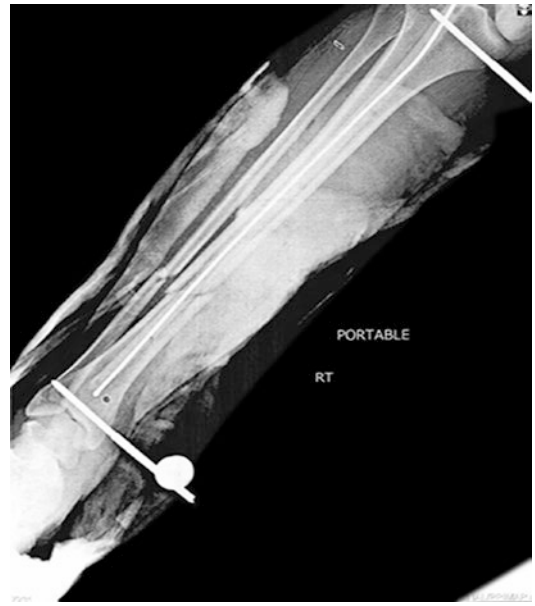

Fig. 39.25 Radiographs showing provisional fixation with external fixator and antibiotic nail

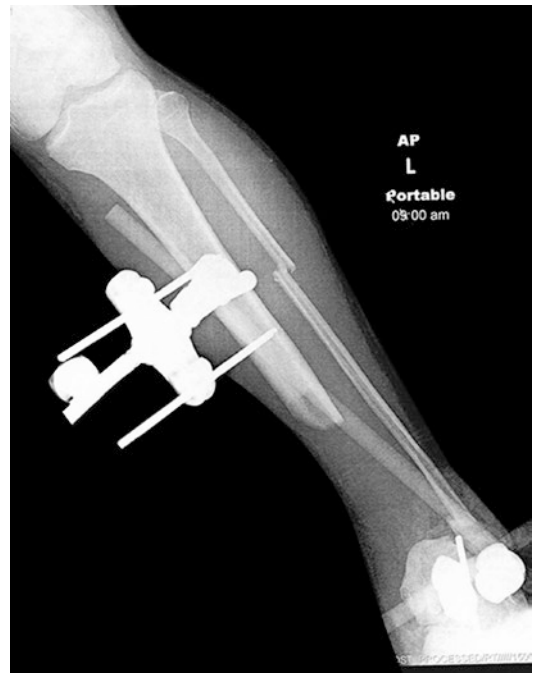

Fig. 39.26 Radiograph demonstrating substantial bone loss from the midshaft of the tibia extending distal to the ankle joint

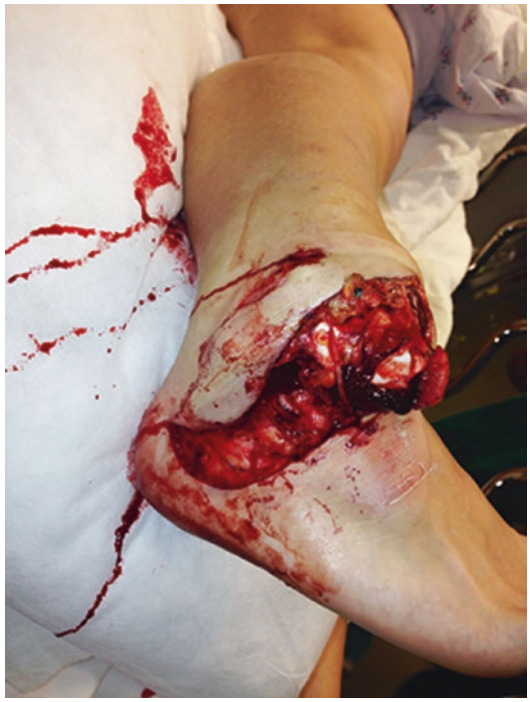

Fig. 39.27 Open fracture with associated soft tissue injury

Fig. 39.28 Pins

Fig. 39.29 Clamps

Table 39.1 Indications for external fixators [9, 11]

Severely comminuted long bone fractures (e.g., tibial shaft and femur fractures)
Open fractures with soft tissue injury (Fig. 39.27)
Complex, intra-articular fractures (e.g., pilon, tibial plateau, distal femur, distal radius, and distal humerus fractures)
Unstable pelvic ring injury (e.g., open book pelvis injury)
Closed fractures with soft tissue injury
Unstable ligamentous injuries (knee and elbow dislocations)
Fractures with significant bone loss
Critically ill patient unable to tolerate operative procedure
High-risk patient for definitive treatment with internal fixation
Reconstruction
Malunion
Nonunion
Arthrodesis
Osteomyelitis
Deformity correction
Limb lengthening
Congenital deformities
Acquired deformities

tissue injuries and body habitus. As external fixators have continued to evolve, the same basic materials are used to build each frame. These devices are constructed using pins or wires (Fig. 39.28), clamps (Fig. 39.29), and bars/rods or rings (Fig. 39.30).

Pins or wires serve to attach the fixator to the bone. Most pins are made of stainless steel or titanium. There are several different pin options available with different lengths and diameters, and many offer varying degrees of tapering. There is also the choice between threaded or smooth pins. The general rule in pin selection is to select a pin with a diameter less than 1/3 the diameter of the bone; selecting the appropriate pin diameter helps to decrease the risk of associated pin site fracture [10]. Clamps are used to attach the pins or wires to the rods or rings of the frame. They also can attach two or more bars/rods together, as seen with spanning external fixators. The bars/rods or rings make up the frame itself and provide the structural support to stabilize the fractures. Just like the pins, the bars/rods and rings come in varying lengths and sizes to

Fig. 39.30 Ring and bars/rods

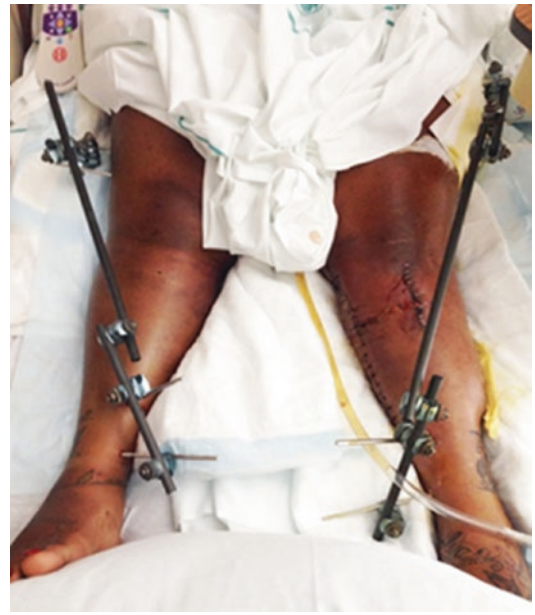

Fig. 39.31 Bilateral spanning external fixators in a polytrauma patient with associated soft tissue and vascular injury

provide options for fixation. Bars/rods span the fracture or joints, stabilizing the proximal and distal fragments and providing alignment and rigidity. Circular rings are often used to provide circumferential access to the limb and protect the skin while providing elevation, potentially eliminating pressure ulcers.

Frame Types

There are several types of external fixation devices, each one able to be tailored to the location of injury, the fracture pattern, and the patient. Fixators function to stabilize fractures by compression, distraction, or applying neutral forces [10]. The basic types of fixation devices include standard frames, joint spanning and articulated frames, and circular frames. Standard frames utilize rods/bars and are primarily used to treat diaphyseal fractures, or fractures of the long bones, including the tibia, femur, humerus, and forearm, and allow for joint range of motion. Conversely, spanning external fixators are used for intra-articular fractures or in injuries with ligamentous instability, vascular injuries, or severe soft tissue compromise (Fig. 39.31) and span the joint which prohibits range of motion in the affected joint.

With joint spanning fixation, the affected joints are immobilized to promote stability of the site of injury and surrounding tissues, to facilitate healing. Articulated frames are also utilized in ligamentous injuries, such as knee dislocations, and intra-articular fractures, although they may allow for partial to full range of motion in the affected joint. These frames are more specialized with more specific indications than other devices. Circular or ring fixators, such as the Ilizarov frame or Taylor spatial frame, are used for limb salvage in severe acute injuries to the lower extremity and in cases of limb reconstruction or deformity correction. These frames are usually more complex and utilize rings, bars, struts, and telescoping rods (Figs. 39.32, 39.33, and 39.34) [10].

Struts are used to correct angular deformities, and telescoping rods are used for distraction to repair bone defects or limb length discrepancies. These techniques involve active participation by the patients, as they follow a program to adjust the struts and bone transporters on their own, mainly in the outpatient setting (Fig. 39.35). As

Fig. 39.32 Ring fixator utilizing struts

Fig. 39.33 Ring fixator utilizing struts—lateral view

Fig. 39.34 Ring fixator utilizing telescoping rods for distraction

research and technology continue to evolve, the implications for use of external fixators have become more commonplace in acute care hospitals worldwide.

Advantages

External fixators have become paramount in DCO due to their wide variety of indications, ease of application, and ability to stabilize fractures and soft tissues in the injured extremity. In the critically injured, polytrauma patients, these devices offer a minimally invasive solution to temporarily and effectively manage their orthopedic injuries until definitive treatment is amenable (Fig. 39.36). These devices provide

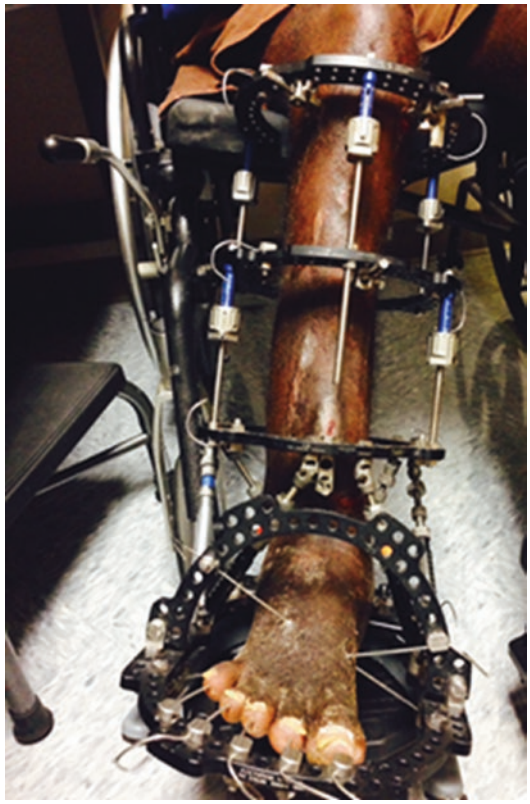

Fig. 39.35 Ring fixator used on a patient with limb length discrepancy as a result of bone loss from a prior trauma

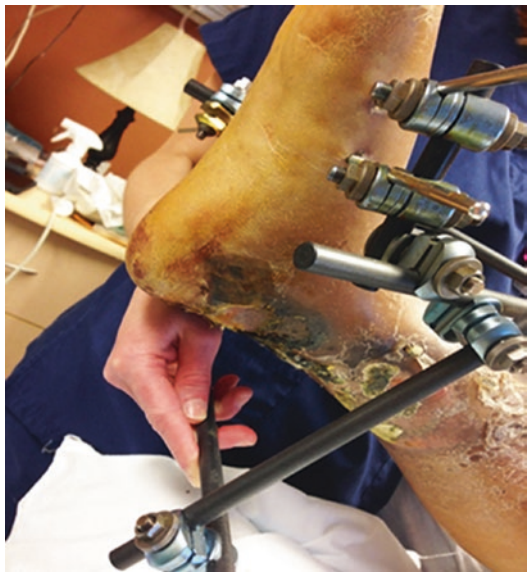

Fig. 39.36 Temporary external fixation due to associated soft tissue injury

stabilization away from the injury site, minimizing further damage to surrounding neurovascular supply [11] and other tissues.

Disadvantages

As with any type of fixation, external fixators have their own associated risks. One common complication is pin site infections, which can range in severity from superficial drainage from the pin tract, surrounding cellulitis, to deeper infections such as osteomyelitis [9]. Pin tracts provide a direct link from the outside environment to the bone and thereby can increase incidence of infections. Increased tissue mobility around the pin site also increases infection risk [9]. Usually pin site infections are superficial and localized, presenting with erythema around the pin site and purulent drainage. Once identified, early pin tract infections can be easily treated with proper hygiene, a short course of antibiotics, or removal of the pin or wire involved [9]. If the soft tissues are irritated due to increased mobility, wrapping a dressing around the pin site will help decrease tissue motion [9]. In cases where pin site infections track deeper into the bone, formal debridement or curettage of the pin site is often required coupled with antibiotic therapy [9]. If untreated, superficial pin site infections can progress to osteomyelitis. Early identification of pin tract infections is critical to minimizing further progression and long-term complications. Educating the patients, their families and caretakers, and clinical staff on the signs of potential pin site infection is important once discharged from the acute care setting. It is crucial to educate the patients and their families that keeping the pin sites clean and dry and minimizing tissue mobility, along with safe cleansing practices, are imperative to preventing pin site infections [9]. Institutions vary on specific methods of daily pin site care, but good basic hygiene is the underlying goal. Patients are encouraged to shower daily and cleanse both the affected extremity and the device with warm soapy water (Table 39.2).

While the relative stability of these devices is advantageous, if the construct is too rigid, the

Table 39.2 External fixation: advantages and disadvantages [6, 9]

Advantages	Disadvantages
Wide variety of indications	Pin tract infections
Versatile	Superficial → Osteomyelitis
Minimally invasive	Delayed union/nonunion
Rapid application	Malunion
Use in critically ill and polytrauma patients	Injury to nerves/vessels
Can be temporary or definitive (Fig. 39.37)	Failure of fixation
Stable (depending on the construct)	Joint stiffness, contractures
Stabilize away from zone of injury	Compartment syndrome
Able to use with soft tissue defects or in the setting of infection	

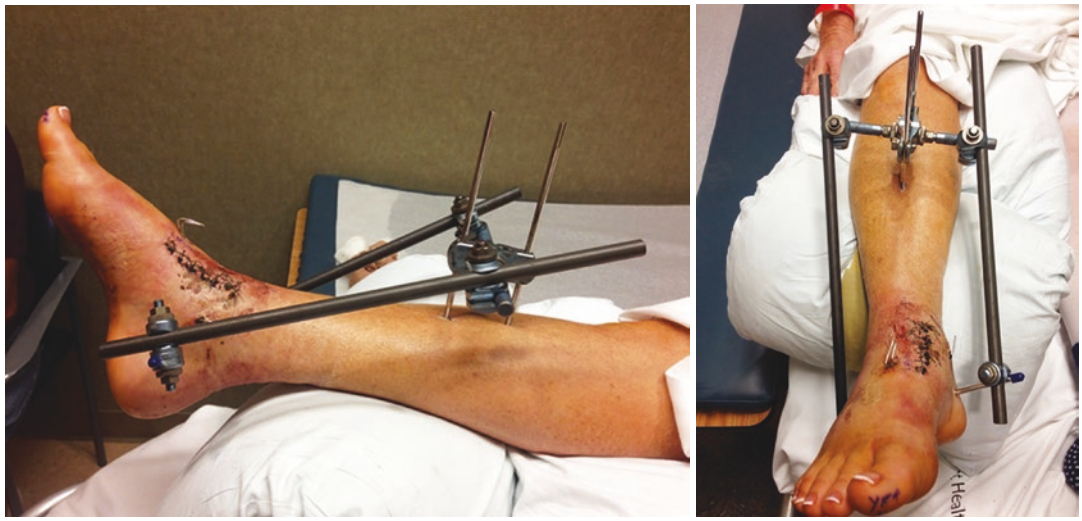

Fig. 39.37 Definitive treatment of a distal tibia intra-articular fracture using external fixation

risk of fracture nonunion occurs. Bony callus is stimulated by micromotion at the fracture site. Without localized motion, callus formation is impaired and the fracture does not heal causing delayed or nonunion ([6], p. 130). Additional potential complications include fracture malunion, joint stiffness, injuries to surrounding nerves and vasculature, compartment syndrome, and hardware failure [9, 12].

With any intervention, proper care and monitoring is essential to decrease complications. Whether it is cast or splint care, traction pins, or external fixation devices, patient assessment on a regular basis is crucial to ensuring that the appropriate treatment is delivering the desired results without complications.

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Compartment Syndrome and Fasciotomies

40

Janet Evelyn Lucia Syme

Introduction

Compartment syndrome has been largely discussed since it was first described in 1881 by Volkmann [1]. Compartment syndrome has since been described as either acute or chronic in nature. This chapter will focus specifically on acute compartment syndrome. Acute compartment syndrome (ACS) is defined as a progression of increasing interstitial pressure within a closed fascial compartment resulting in decreasing profusion to the tissues within the compartment which over time causes ischemic injury including muscle necrosis, irreversible nerve damage, contractures, and loss of limb. ACS can be caused by crush injuries, high-energy injuries, blunt or penetrating trauma, fractures, soft tissue injuries, internal bleeding, arterial injury, prolonged compression, burn injuries, excessive exercise, snakebites, prolonged immobilization, or malpositioning during surgery.

The classical description of acute compartment syndrome has been the "5 Ps" (pain, paresthesia, paralysis, pulselessness, and pallor). In most test questions, the vignette describes the patient having all "5 Ps" and the correct diagnosis in the test being compartment syndrome followed by treatment with fasciotomy. In reality compartment syndrome is a progression towards all five of the classic signs and symptoms [2, 3]. Clinically the goal is to identify compartment syndrome early and treat prior to the patient having all the classic "5 Ps." Otherwise the patient is left with a pulseless blue leg that is no longer salvageable, cannot undergo fasciotomy, and increases morbidity, and this outcome could have been preventable [2, 4].

Prolonged ischemia caused by acute compartment syndrome (ACS) can lead to irreversible muscle necrosis, nerve damage, contractures, and loss of limb. In order to prevent these irreversible injuries, it is important to understand the correct timeline of the signs and symptoms associated with ACS. The first symptom is pain, but since ACS can occur in a trauma setting, it can be difficult for the clinician to determine if the pain is associated with another distracting injury, the trauma that caused ACS (i.e., fracture or burn injury), or if it is the first indicator of ACS. The current recommended evaluation of pain includes a "significant discomfort with passive stretching of the affected tissues" or a description of "pain that is increasing and/or unusual pain out of proportion" [4]. In children or adults with learning disabilities, the pain associated with ACS has been described as the 3A's: anxiety, agitation, and increased need for analgesia [5].

After time has passed since the onset of pain, the "pressure-induced ischemia affects the

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conductivity of the nerves in the compartment, and a painless state will ensue" [4]. Paresthesia typically indicates the beginning of nerve ischemia, and within 4–6 hours, the paresthesia can turn into hypoesthesia or anesthesia, indicating irreversible nerve damage [6]. Since both pain, swelling/firmness to palpation, and paresthesia are subjective, it is difficult to assess these findings in patients who are not awake and/or in patients whose pain is masked by analgesic treatments such as regional anesthesia or increased narcotic dosages [4]. Late signs have been noted to be paralysis, pulselessness, and pallor at which time the indicated treatment of fasciotomy can be contraindicated [2, 4, 7]. At the time of late signs and symptoms or a missed diagnosis, the sequela includes functional impairments (such as foot drop or Volkmann's contractures in the upper extremity), dysesthesias, crush syndrome, metabolic acidosis, cardiac arrhythmia, renal failure, rhabdomyolysis, systemic infection, permanent disability, medicolegal consequences, loss of limb/amputation, and possibly death [4, 8].

The pathophysiology of ACS has been extensively researched in order to determine if a more empirical method of diagnosis can be reliably achieved. The normal intracompartmental or interstitial pressure (ICP) is 8–10 mmHg in adults and 10–15 mmHg in children, which is less than the perfusion pressure in the capillary beds [6, 9]. During ACS the ICP increases greater than the perfusion pressure of the capillary beds causing hypoperfusion of the musculature within the compartment. This ischemic condition can lead to irreversible damage as the compartment pressure continues to increase and as the length of time increases before surgical decompression of the intracompartmental pressure can occur. The amount of intracompartmental pressure required to cause damage has been disputed in the literature. In the past an absolute pressure of >30 mmHg has been considered a baseline value by several researchers in order to perform a fasciotomy [10–12]. Other researchers have questioned using absolute values [3]. One group proposed one of the current preferred methods which is calculating the difference between the patient's diastolic pressure and the measured intracompartmental pressure (Δp = diastolic blood pressure – intracompartmental pressure) [13]. They have suggested that a $\Delta p > 30$ mmHg is indicative of ACS and requires promptly performing a fasciotomy. A follow-up study demonstrated the value of calculating the pressure difference, and it is now the calculation most often used [14].

ACS is a clinical diagnosis, but due to various factors, a clinical diagnosis can be difficult to achieve. If a clinical diagnosis can be made, then surgical intervention should be performed expeditiously. If there is still doubt, the ICP can be measured. A transducer is connected to a catheter and inserted into the muscle bed via aseptic technique. There are several pressure measurement devices available. The more common devices are the Stryker Intracompartmental Pressure Monitor System, arterial line manometer, and Whitesides apparatus. These were all tested by Boody et al. with straight needle, side-port needles, and slit catheters. Their findings were that the arterial line manometer with a slit catheter showed the best correlation, while the Whitesides apparatus with the side-port needle showed the worse results. Overall the side-port needles and slit catheters were more accurate than straight needles, and the arterial line manometer was the most accurate device with the Stryker being very accurate as well [15]. Other researchers have investigated various bedside diagnostics aids for ACS such as MRI, ultrasound, scintigraphy, continuous ICP, and near-infrared spectroscopy, but further investigation is needed to prove reliability and accuracy for clinical diagnosing purposes [6].

Treatment

During the thorough physical exam of the affected limb, the skin must be exposed to identify any constrictive dressings, penetrating traumas, deformities indicative of fractures, or any evidence of soft tissue injury in order to fully treat the patient. Since fractures and high-energy traumas are the leading causes of acute compartment syndrome, these other injuries must be

identified as many treatments will occur simultaneously.

The definitive treatment for compartment syndrome is fasciotomy of the affected compartments. Surgical decompression of the involved compartments has been recognized as the definitive treatment of compartment syndrome since it was first discussed in 1924 by Dr. Paul Jepson [16]. This is typically done in the operating room and possible during the same surgery to repair or stabilize any concurrent fractures. Mobile operating rooms set up at bedside are only used in extreme cases of combat trauma or if a patient in the intensive care unit is too unstable to make a trip to the operating room.

Time to treatment is essential in avoiding irreversible damage. The patient must be treated with fasciotomy within 2 hours of diagnosis and before 6–8 hours from the event [6]. Determining when the start of the event occurred may be difficult especially with trauma patients who are unresponsive. Reversible muscle damage has been estimated to occur before 3–4 hours of ischemia, and irreversible muscle damage occurs after 8 hours of ischemia. Neuropraxia has been seen within 4 hours of increased ICP ischemia, and irreversible nerve damage occurs after 8 hours of increased ICP ischemia. After the diagnosis of compartment syndrome has been made, every effort to quickly perform a fasciotomy by the surgical team should be made, and the team should not wait until further work-up for other injuries is done, such as x-rays or bloodwork.

After fasciotomy, during reperfusion of the compartments, depending on the amount of ischemic damage, the patient's system can be introduced to the toxic effects of possible necrotic tissue. The patient must be assessed for hypovolemia, metabolic acidosis, and myoglobinemia. This is most important to reduce the incidence of renal failure, rhabdomyolysis or crush syndrome, hyperkalemia, cardiac arrhythmias, multiple organ failure, or death. Intravenous fluids should be given and regular labs drawn and monitored.

When a fasciotomy is performed, it requires an adequate incision and facial release. Minimally invasive exposures should only be done by extremely knowledgeable staff as the full length of the fascia can be missed with the longitudinal incisions. All compartments must be released with preservation of vital structures, and a through irrigation and debridement must be undertaken at the time of initial intervention. Patients typically return to the operating room in 48–72 hours for a second look to assess the viability of the tissue.

Fasciotomies are not performed when the extremity is nonviable from prolonged tissue ischemia. A clinically cold extremity with muscle rigor, complete neurological loss, and absent inflow by Doppler is known as grade 3 ischemia. This is irreversible and is generally contraindicated for reperfusion or other limb salvage. The surgical teams who typically perform fasciotomies in your institution should still be contacted when a missed or delayed compartment syndrome is found in order to monitor the patient who may possibly undergo an amputation or other surgical treatments if the necrotic tissue becomes infected which could possibly lead to a systemic blood infection with multiple end-organ failure.

Lower Extremity

The number one cause of compartment syndrome in the upper or lower extremity is a tibia fracture and most frequently a high-energy injury among young men [17]. The other common causes of lower extremity compartment syndrome are noted as a high-energy soft tissue injury and crush syndrome [17]. The lower extremity is composed of 16 compartments which are separated below by 3 general areas of the lower extremity.

*There are three compartments in the thigh:

1. Anterior: sartorius, quadriceps, femoral artery and nerve
2. Medial: gracilis, adductors, external obturator, deep femoral artery and vein, obturator nerve
3. Posterior: biceps femoris, semitendinosus, semimembranosus, sciatic nerve

*Some surgeons consider the vastus intermedius to be a 4th compartment.

There are four compartments in the lower extremity:

1. Anterior: tibialis anterior, extensor hallucis longus, extensor digitorum longus, peroneus tertius, anterior tibial artery, deep peroneal nerve
2. Lateral: peroneus longus and brevis, superficial peroneal nerve
3. Superficial posterior: gastrocnemius, plantaris, soleus, sural nerve
4. Deep posterior: tibialis posterior, flexor hallucis longus, flexor digitorum longus, popliteus, posterior tibial artery, tibial nerve

There are nine compartments in the foot:

1. Medial
2. Lateral
3. Four interossei
4. Three central

Compartment syndrome in the thigh is less common than in the lower leg and can be treated with one or two incisions. Fasciotomies to the thigh have a higher risk of infection and morbidity when compared to the lower leg [6].

Traditionally two incisions are made to release the compartments of the tibia (anterolateral and posteromedial incisions). Shorter incisions carry a higher risk of incompletely decompressing all four compartments of the lower leg. The anterolateral incision begins from a straight line between 5 cm distal to the fibular head and 5 cm proximal to the tip of the lateral malleolus. Care should be taken at the distal end of this incision to avoid damaging the superficial peroneal nerve. From this incision the anterior and lateral compartments can be released. The posteromedial incision is a straight line from 2 cm posterior to the medial aspect of the tibia with care taken to avoid damage to the saphenous nerve and vein. Through this incision the posterior compartments can be released. There are limited articles advocating for a single incision compared to a double incision for the lower leg fasciotomy. Recent research articles have advocated for a single incision to reduce risk of infection and scarring and avoid formation of tenuous skin bridge or fracture devitalization [18, 19]. One study reported no difference in infection, time to wound closure, rates of STSG, or nonunion rates between a single and dual incision fasciotomy approach [20]. There are varying techniques with single incision, and they are not widely taught. The decision between single and double fasciotomy incision for the lower leg is ultimately made by the surgeon based on experience [20].

Fasciotomies for compartment syndrome in the foot can lead to excessive scarring, disability, and risk of damaging the plantar neurovascular bundle.

*All fasciotomy incisions should not be closed during the first operation in order to avoid recurrence of compartment syndrome. Fasciotomy wounds will need to have a planned staged closure in a following operation to allow for full compartment release and reduction of swelling.

Upper Extremity

Within the upper extremity, compartment syndrome most commonly affects the dorsal and volar compartments in the forearm [7]. The most common cause of compartment syndrome in the forearm is a high-energy distal radius fracture which is more commonly found in men under the age of 35 [17]. The second most common upper extremity compartment syndrome is due to a soft tissue injury with no fracture [17]. The upper extremity has a total of 15 compartments; below, these compartments are separated into 3 areas within upper extremity.

Upper arm has two compartments:

1. Volar (flexor): biceps brachii, brachialis, coracobrachialis, musculocutaneous nerve, brachial artery, median nerve, basilica vein, medial cutaneous nerve
2. Dorsal (extensor): triceps brachii, ulnar nerve, profunda artery, radial nerve

Forearm has three compartments:

1. Volar: Flexor carpi radialis and ulnaris, flexor digitorum superficialis and profundus, flexor pollicis longus, flexor digitorum profundus, ulnar nerve and artery, median nerve and artery, superficial branch of the radian nerve, anterior interosseous artery and nerve
2. Dorsal: posterior interosseous nerve and artery, extensor carpi ulnaris, extensor pollicis longus, extensor digitorum communis
3. Lateral (mobile wad): brachioradialis, extensor carpi radialis brevis and longus

*Some consider the pronator quadratus as the 4th forearm compartment, although the deep volar muscles are typically damaged during compartment syndrome.

Hand has ten compartments:

1. Hypothenar
2. Thenar
3. Adductor pollicis
4. Four dorsal interosseous
5. Three volar interosseous

Compartment syndrome of the upper arm is rare and is usually associated with a humerus fracture; therefore, the incision for the open reduction internal fixation of the humerus fracture can be used to release the compartments. Otherwise fasciotomy for the upper arm compartments can be made through a single medial or lateral incision. In some cases of compartment syndrome of the hand or the volar compartment of the forearm also cause the pressures with in the carpal tunnel to elevate requiring release of the transverse carpal ligament along with fasciotomy of the compartment(s) [7].

An incision to release the volar forearm compartment can be made longitudinally beginning just radial to the flexor carpi ulnaris, avoiding median nerve and artery, at the wrist (potentially to extend distally for carpal tunnel release) and can be extended proximally to the medial epicondyle and finally curved radially toward the antecubital fossa. After decompression of the volar forearm compartment, the dorsal and mobile wad compartments should be checked and may have decompressed during the release of the volar compartment. If not, then a dorsal longitudinal incision is used to release the dorsal forearm compartment. This straight incision begins 3 cm distal to lateral epicondyle toward the midline of the wrist to Lister's tubercle. If forearm compartment syndrome is caused by fractures, then forearm incisions can also be altered by an orthopedic surgeon to obtain open reduction internal fixation of forearm fractures.

To avoid contractures in the hand, it is recommended to perform the hand incisions in accordance to the Brunner type. After skin incisions are made over the effected compartments, blunt dissection is performed, the fascia is cut while protecting deeper structures, and the compartments are manually inspected to ensure full release of the compartments.

*All fasciotomy incisions should not be closed during the first operation in order to avoid recurrence of compartment syndrome. Fasciotomy wounds will need to have a planned staged closure in a following operation to allow for full compartment release and reduction of swelling.

Wound Care and Closure

Fasciotomy wound closures commonly occur in a delayed or planned staged manner to ensure the absence of infection or necrotic tissue in the wound and sufficient decrease of surrounding tissue edema in order to allow for safe closure of the skin and to avoid premature closure of the fasciotomy wound leading to recurrence of compartment syndrome [6]. Currently there are several techniques used for the final stage in the process of closing a fasciotomy wound. Which technique is used in closing a fasciotomy wound is dependent on the surgeon's experience and the most recent validated research data.

In 1997 Argenta and Morykwas introduced a vacuum-assisted wound closure (VAC) that applied subatmospheric pressure (125 mmHg below ambient pressure) with a foam dressing to promote wound healing [21]. Since the introduction of the wound VAC (negative pressure wound

dressing), several studies have demonstrated that the wound VAC system is a more effective technique for enhancing and expediting open wound closure rates when compared to traditional methods such as wet-to-dry dressings [22, 23]. The wound VAC has been shown to increase angiogenesis, promote granulation, decrease wound edema, decrease infection rate, expedite wound healing or closure time, decrease hospital length of stay, and promote successful adherence of split-thickness skin grafts (STSG). Currently wound VACs are applied to fasciotomy wounds at 125mmHG below ambient pressure on a continuous setting until the wound is ready to be closed surgically. Although the intermittent setting has been described in the animal model, it has been noted that the intermittent setting causes deflation/re-expansion of the foam allowing for motion in the wound and creating pain for the patient [22].

Premature closure of fasciotomy wounds has been demonstrated to result in a recurrence of compartment syndrome, and therefore the timing of fasciotomy wound closures varies [24]. Following the initial fasciotomy surgery, most fasciotomy wounds are brought back to the operating room within 48–72 hours for a repeat irrigation and debridement (I&D) [6]. During the repeat I&D, the surgeon will evaluate for any development of necrotic tissue, appearance of infection, and possibility of closure. Any necrotic tissue must be debrided surgically to prevent infection. If necrotic tissue is present during a repeat I&D, then the necrotic tissue must be sufficiently debrided surgically. After debridement the wound is dressed with a wound VAC, and the patient is scheduled for another I&D within 48–72 hours to reevaluate the wound. Once the surgeon is satisfied that the wound does not have any necrotic or infected tissue, then the wound's skin edges are manually approximated to determine if primary closure is possible. Primary closure of the skin edges is the preferred method to avoid further complications, but many fasciotomy wounds are unable to be closed in such a manner and several are closed with a STSG [6, 25]. A wound VAC is then applied to the but many surgeons place a petrolatum-impregnated gauze between the graft and sponge [22].

Primary closure may not be attainable due to the retraction of skin, surrounding edema, and expansion of the muscle belly into the wound following fascia decompression [26]. Many medical centers perform STSG to close fasciotomy wounds, but STSG causes scarring, creation of a second wound, insensate wound, esthetically unsatisfactory wound, and potential graft failure. There have been new surgical techniques proposed for closure of fasciotomy wounds such as using rubber band-assisted closure or closure with silastic vessel loops with daily gradual bedside tightening "shoelace technique" [26, 27]. Many of these new techniques will need to be researched further to determine if one technique or a combination of techniques improves patient outcomes. Some researchers have recommended that if the fasciotomy wound is not able to be closed, then electing for early STSG of the fasciotomy wounds would decrease hospital length of stay since serial repeat I&Ds may not result in delayed primary closure [25]. Currently the timing between initial fasciotomy and final closure along with the technique used varies, and further studies are needed to establish a standard.

Medicolegal Complications

Acute compartment syndrome is an extremely contested issue if not properly diagnosed and treated in a timely manner. Compartment pressures in these cases were not measured or measured incorrectly with malpositioning of the hardware. A study demonstrated a linear relationship between the amount of cardinal physical exam findings/signs missed, the time from presentation to treatment with fasciotomy, and the amount of payment received in litigation to the patient [28]. The same study suggested a breakdown in communication between members of the medical team regarding the patients' signs and symptoms [28]. As stated previously, the diagnosis of compartment syndrome should be made clinically; if there's any doubt, the treating prac-

titioner should trust his or her judgment rather than a number that may have been obtained incorrectly and perform the intervention. Importance is stressed in avoiding any delays to diagnosis and treatment in order to prevent irreversible damage due to ischemia of the tissue within the compartment.

Anticoagulation Therapy Contraindications

Many patients are on antiplatelet or anticoagulation therapy. There is no contraindication with any of these agents. Warfarin is one agent that is easily reversed if needed with vitamin K or fresh frozen plasma (FFP). There is however a growing concern over Xa inhibitors including Xarelto, Eliquis, and Lixiana. There are no known reversal agents, and FFP has no effect given the direct factor-inhibiting effect. However, the risk of limb loss, chronic limb dysfunction, or death with compartment syndrome is so high that intervention should likely take place with meticulous hemostatic techniques being used. Skin edge bleeding must be addressed and the use of thrombotic agents including Floseal, Tisseel, Surgicel, or StatSeal. If wound VAC is used, then the patients' drainage into the canister must be closely monitored for possible large sanguineous amounts of drainage. CBCs should be routinely taken to monitor their hemodynamic status following their fasciotomy surgery.

Summary

Acute compartment syndrome is a surgical emergency requiring quick clinical decision-making and clear understanding of the anatomy for successful decompression of the involved compartment(s). All patients with a clinical suspicion of ACS should be followed closely with serial examinations in order to prevent any delay in diagnosis. Treatment with fasciotomies must be initiated within 6–8 hours from the event, and surgery must be performed within 2 hours of diagnosis in order to prevent significant morbidity.

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Wound Management in the ICU

41

Andrew M. Nunn, Allie Thompson, and Ian M. Smith

Introduction

The management of wounds in the critical care setting is a complex task and if underestimated can result in devastating outcomes for patients. Patient comorbidities, associated injuries, and systemic inflammation all play critical roles in the healing process. The wound healing process encompasses three basic phases: inflammatory, proliferative, and remodeling. The inflammatory phase lasts for several days and begins immediately after injury, with both platelet aggregation and activation of clotting factor to promote hemostasis. Fibrin, newly converted from fibrinogen, then binds this platelet plug forming a scaffolding around the wound. Vasoconstriction initially ensues, decreasing blood loss and allowing clot formation. Upon successful formation of a clot at the locally injured area, subsequent vasodilation occurs, increasing local blood flow to the wounded area to support wound repair and the newly created clot. Chemotaxis results in migration of inflammatory cells such as neutrophils, macrophages, and eventually lymphocytes a few days later. The lymphocytes begin to phagocytize bacteria and release enzymes that degrade necrotic tissue. Macrophages also begin to secrete growth factors and cytokines that are critical to wound healing. During the proliferative phase, fibroblasts begin to deposit collagen within the wound. Neovascularization and angiogenesis occur during this phase, resulting in new capillary formation within the local injury. The result of this stage is granulation tissue and epithelialization from the periphery of the wound. The final stage of healing, remodeling, then begins within 2–3 weeks and lasts for several months. Type III collagen is eventually replaced by type I collagen, as collagenases perform extensive remodeling. Throughout this phase, the tensile strength of the wound steadily improves as it returns to 70–80% of its original strength [1–3] (Fig. 41.1).

While primary closure is preferred to optimize wound healing, this is often not feasible in the critically ill patient. Open wounds generally fall into two broad categories: the soft tissue defect and the open abdominal cavity (which is discussed elsewhere in this text). Large soft tissue defects occurring after injury may preclude primary closure, or closure may be deliberately avoided due to potential for infection or significant contamination. Other factors such as compartment syndrome and limb ischemia may also make primary closure unsafe.

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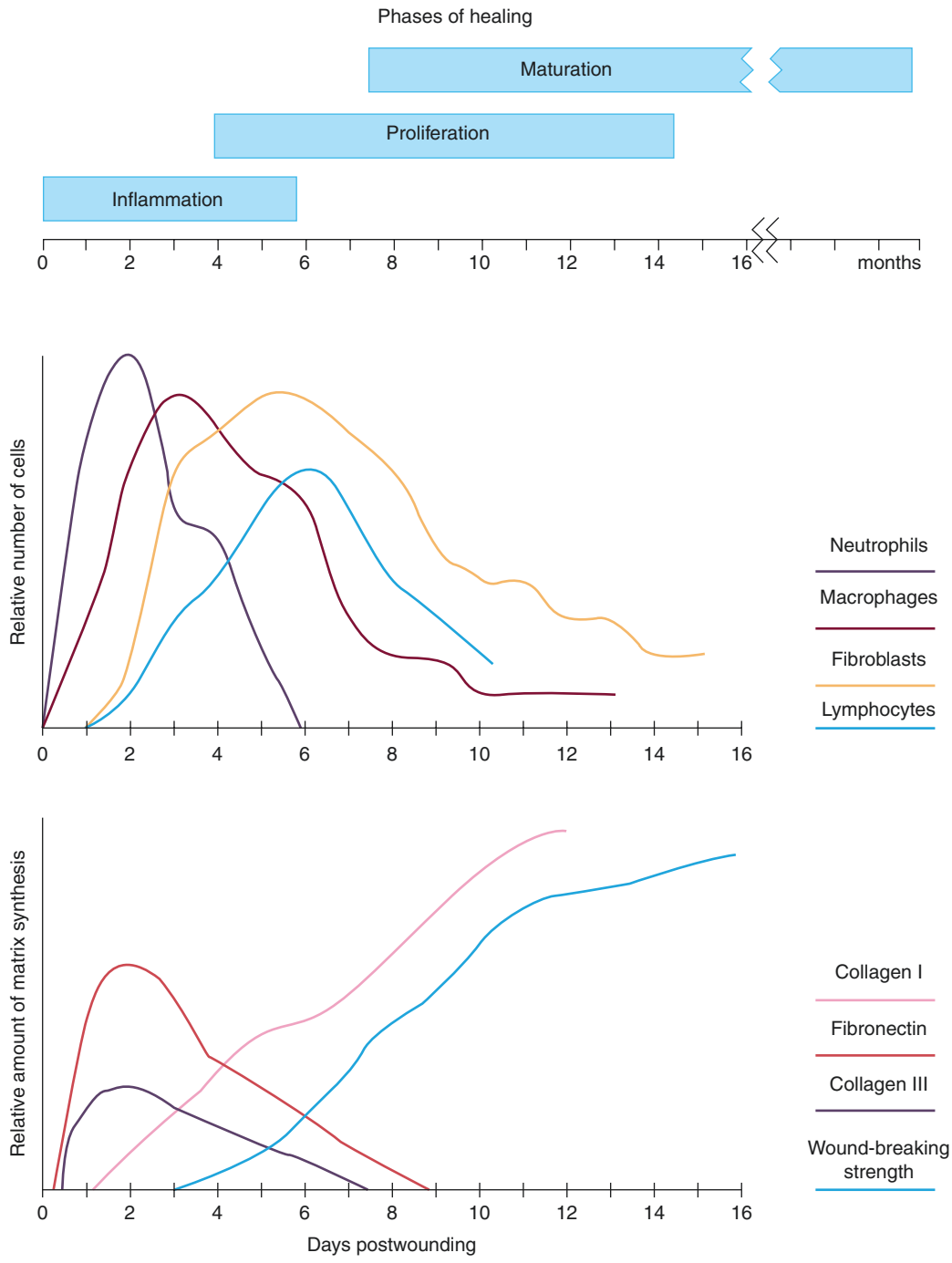

Fig. 41.1 Phases of wound healing. (Reprinted from Nazzal et al. [27]. With permission from McGraw-Hill Education)

When primary closure is not an option, wound management is best achieved with wound coverage and packing or via negative pressure dressings. In either case, the ideal dressing should provide balance between absorption of excessive fluid and simultaneously keeping the wound adequately moist so as to promote tissue rejuvenation. Both animal

and human studies have shown accelerated healing, faster wound contraction, and faster granulation with re-epithelialization of tissue in a moist environment [4, 5]. The dressing should also eliminate dead space, as this can be a nidus for excessive fluid accumulation which may precipitate further infection and impaired healing. Additional considerations when choosing a dressing must include the amount of pain induced, durability of the dressing, and cost-effectiveness.

Basic Wound Care

While this chapter focuses on the treatment of wounds, the condition of the host (patient) cannot be ignored. Maintaining normal physiology and nutritional status is paramount to wound healing. Acute wounds should first be thoroughly irrigated of any visible debris. For large wounds, this is often best accomplished in the operating theater or with anesthesia at the bedside. For chronic or infected wounds, sharp excisional debridement may be necessary to remove infected and devitalized tissue. After a wound has been cleaned, it should be covered with a dressing to create an environment supportive of healing. The ideal dressing protects the wound and creates a moist, clean environment. Many different dressings are available to help achieve an ideal wound environment. Three broad categories of dressings exist: those that promote host autolysis of tissue, those that promote a moist environment, and those that control the bacterial load [6]. Traditionally, wound packing with wet-to-dry gauze dressings has been the modality of choice for large soft tissue defects, even as support continues to decrease for wet-to-dry gauze being considered standard of care [5]. Saline-soaked gauze is placed into the wound to ensure elimination of dead space while allowing for wound drainage and continued absorption providing a moist environment for healing to occur. The gauze may be soaked in a myriad of solutions (normal saline, hypochlorite-based solutions, sulfur-based solutions, silver nitrate) when acute or persistent wound infection is a concern. The selection of solution is dependent on the microbiome of the wound associated with the nidus of injury. One such solution, Dakin's solution, also known as buffered sodium hypochlorite (a chlorine-based solution), was originally developed as a topical antiseptic for wound treatment during World War I [7]. It is one of the most common solutions used on dressings in contaminated and dirty wounds and often added with suspicion of fungal contamination as well. The chemical composition of Dakin's is a mixture of hypochlorous acid, hypochlorous anion, and dissolved molecular chlorine. These components exert an oxidative effect which results in antimicrobial activity [7]. One downside to the use of this sort of antimicrobial is the nonselective mechanism of action on host cells which results in tissue toxicity. Studies have clearly shown that Dakin's inhibits host cell function [8, 9].

Recent studies have yielded disappointing data regarding the antimicrobial and antifungal effect of Dakin's. Numerous in vitro studies have reported evidence of concentration-dependent cytotoxicity and functional decrement in human tissue exposed to Dakin's solution due to increased losses in phagocytic capability associated with macrophage toxicity. Prolonged use of Dakin's or use of more highly concentrated solutions can disrupt the wound healing process by impairing the function of infiltrating monocytes and neutrophils during the initial inflammatory phase which simultaneously harms the fibroblast and endothelial cell populations necessary for later proliferation and restorative phases [7]. In summary, Dakin's and other chlorine antimicrobial solutions may impede wound healing. The practitioner must weigh the benefits of the solution's anti-infective properties against the risk and should only use such solutions for a short duration.

Regardless of the liquid used to moisten the gauze, the wet gauze is covered with dry gauze to prevent the wound from drying out and remains in place until dried. With each packing change, the removal of the dry dressing aids in further debridement of devitalized tissue. Wet-to-dry wound packing is especially useful in the case of

dirty or infected wounds. The limited materials needed and nominal level of expertise required also make this wound therapy ideal for austere or resource-strapped environments.

When debridement is no longer desired, gauze may also be impregnated with emollient substances such as petroleum to add moisture to the wound and allow for decreased tissue injury at dressing change. Although this dressing additive decreases pain associated with dressing changes, the downside to this type of dressing is the loss of debridement offered by the removal of dry gauze alone.

Foam dressings are sometimes employed and provide removal of excess moisture and exudate from the wound making them ideal in very moist environments [6]. One major advantage to this wound management therapy is the decreased frequency of dressing changes typically required. Therefore, if this type of dressing is employed, one must have a low threshold to remove it and assess the wound if there is any sign of infection. Alginate dressings contain alginic acid (seaweed) and are also very absorbent. They are sometimes mixed with silver for antibacterial properties. These types of dressings are very useful for very moist wounds with a high exudative content [6].

Hydrogels are polymers rich in water. They are useful in wounds that are dry, as they add moisture to the wound bed, thereby facilitating autolysis, and, therefore, are very useful in treating pressure ulcers. Hydrocolloids are a multilayer dressing consisting of a self-adhesive layer that is gel forming and it is absorptive of exudates. The outer layer is protective and helps exclude bacteria from the wound [6].

Many dressings contain silver or are silver based. FDA-approved for wounds in the 1920s, silver is a well-known broad antimicrobial and is used extensively in wounds as it promotes healing and decreases inflammation. It is particularly useful in more superficial wounds and decreases the bacterial burden. There are many variations of wound dressings and applications containing silver including creams, foams, and other dressing types. The common denominator in all of them is the silver cation [10].

Oftentimes a lesion in the ICU is encountered when it is well into the cycle of wound healing, with exudate or eschar present. If eschar or necrotic debris is present, it should be removed to allow for normal wound healing. If surgical debridement is not an option, the use of enzymatic solutions such as a collagenase ointment can aid in the proper treatment of any wound which has begun to epithelialize. Collagenases degrade collagen through the breakdown of peptide bonds [11].

Negative Pressure Wound Therapy (NPWT)

Developed by Argenta and Morykwas in the 1990s, NPWT has been found to be superior to traditional dressings [12]. NPWT promotes more rapid wound granulation when compared to wet-to-dry dressings. The basic components of a NPWT system include a semipermeable conduit used to pack the wound, an occlusive dressing, a suction port, and a collection system. Commercially available kits are most commonly used (V.A.C®, KCI, San Antonio, TX), and these utilize an open-pore polyurethane sponge as the fluid conduit, although other methods may be devised depending on the wound. The goal of the NPWT system is to eliminate the dead space while the pressure gradient generated by the suction promotes excess fluid transport away from the wound, thereby altering the inflammatory environment. The sponge retains enough fluid to keep the wound moist, while the occlusive dressing keeps the wound bed warm and prevents leakage. The sponge will deform under the negative pressure, thus causing tissue deformation which will stimulate tissue remodeling. The basic mechanism of action can be broken down into macrodeformation (reapproximation of edges), microdeformation (cell stretching and increased proliferation), fluid removal, and environmental control of the wound [13, 14]. Convincing evidence exists for the use of wound vacs in the setting of fracture and soft tissue injury to decrease infections and expedite definitive wound coverage [14–16] (Fig. 41.2).

Indications

In the critical care setting, NPWT is most commonly used for large surface area soft tissue defects or when primary closure of a wound might further propagate increased risk of infection or contribute to the development of compartment syndrome. Large soft tissue defects in the trauma patient benefit greatly from the NPWT in terms of fluid management and macro- and microdeformation. Given several unanticipated factors associated with warfare and wound care, adaptation to management of complex wounds is necessary and has been a driving force in research. Leininger and colleagues demonstrated excellent success of initial management of high-energy wounds with debridement and NPWT, followed by delayed primary closure [17]. Placement of NPWT over muscle is a common practice after fasciotomy. Studies have not shown this to be superior to other management strategies such as the shoelace technique, but it remains a common practice [18]. Lastly, growing evidence supports placement of an external NPWT (i.e., a "skin vac") over high-risk primarily closed surgical wounds, resulting in lower SSI rates and faster healing [19, 20] (Fig. 41.3).

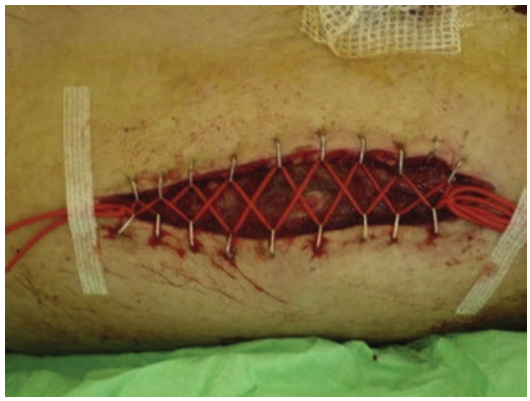

Fig. 41.2 Shoelace technique. (Reprinted from Kakagia et al. [18]. With permission from Elsevier)

NPWT with instillation has become much more commonplace and is a very promising modality to treat dirty wounds. Instillation utilizes a hydrophilic foam (as opposed to hydrophobic foam in traditional NPWT). The system will instill a liquid

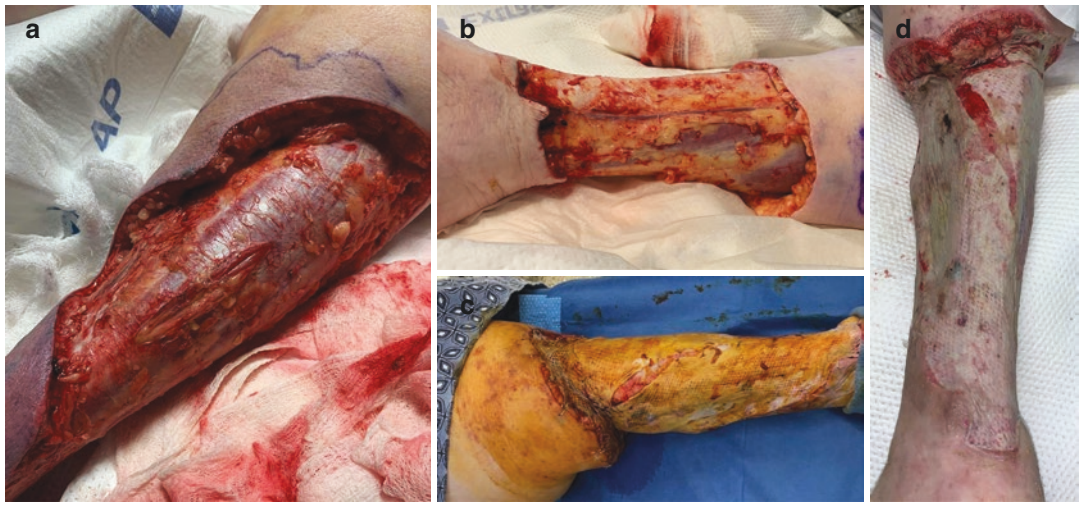

Fig. 41.3 (**a**) Patient with significant past medical history of DM, HTN, and rheumatoid arthritis (on daily steroids) who presented to hospital with chief complaint of left calf pain and swelling × 2 weeks with new-onset lower extremity discoloration. On admission, patient was febrile, hypotensive on multiple vasopressors, with a leukocytosis and acute kidney injury. She previously underwent incision and debridement of left lower extremity skin and soft tissue with exposure of fascia layer. (**b**) Left lower extremity 72 hours after application of negative pressure vacuum-assisted closure device (96 hours after source control) (**c**). Left lower extremity after allograft (10 days after source control) and negative pressure vacuum-assisted closure device × 1 week (17 days after source control) (**d**). Left lower extremity 3 weeks (30 days after source control) after allograft and negative pressure vacuum-assisted closure

solution and allow it to dwell for a set amount of time before resuming suction. Various solutions can be instilled and include saline, Dakin's, and various commercial solutions [21]. Kim and colleagues found no difference in wound healing between the use of simple saline solution and an antiseptic solution, suggesting saline may be favored [22]. For extremely painful wounds, adding lidocaine to the solution has been found to be efficacious [21]. A recent consensus panel recommends use of NPWT with instillation for complex wounds in patients with multiple comorbidities, ASA classification ≥2, severe traumatic wounds, diabetic foot infections, and wounds complicated by invasive infection or extensive biofilm [23]. Gabriel et al. have nicely demonstrated that the use of NPWT with instillation decreases operating room debridements, length of stay, length of therapy, and time to wound closure [24]. These authors have utilized these criteria for NPWT with instillation and have had very favorable results.

Application and Removal

NPWT dressing changes for soft tissue wounds are typically well tolerated by the patient at the bedside. Appropriate analgesia should be provided, which on occasion may include the use of sedation. Prior to removing the existing dressing, the suction should be turned off. The previous dressing should be removed and discarded. If the previously placed sponge has adhered to underlying granulation tissue, it may be soaked in saline for several minutes to facilitate removal. Injection of saline or local analgesia into the sponge using a blunt needle may decrease discomfort of removal. Ensure that the maximum dose of local analgesics is not exceeded if this method is used. Once the sponge is removed, the wound should be irrigated with any residual devitalized tissue debrided. The wound edges must be dry and hemostatic to ensure an optimal environment for the replaced, fresh occlusive dressing to adhere properly and thus minimize the risk of the dressing leaking. Various adhesives such as Mastisol® (Eloquest Healthcare, Ferndale, MI) and compound benzoin tincture can be used to help with drape adherence and decrease leaks.

Once the wound is prepared, the foam sponge is trimmed to fit the size of the wound, ensuring that the sponge edges do not extend past the wound edges. The sponge is placed into the wound, and an adhesive, occlusive covering is placed over the wound with at least a 3–5 cm margin covered around all wound edges. A small hole is created in the central portion of the adhesive covering and occlusive sponge dressing with subsequent placement of the suction port over the defect. In the case of large wounds, more than one suction port may be placed strategically around the wound so as to more evenly distribute negative pressure and optimize granulation capabilities of wound dressing. The suction pump is then connected to the suction port, the pump initiated, and the dressing observed for any evidence of a leak or lack of an airtight seal. Most commercially available suction pumps have an alarm that will alert the practitioner of a potential leak or clog in the suction system.

Wound Closure

Definitive primary tissue wound closure should be the primary goal of all wounds from initial diagnosis, knowing that multiple factors go into this: patient-specific factors such as comorbidities, current clinical status of the patient, and status of the wound. Clinicians must weigh these factors carefully in their approach to wound closure, as risks and benefits abound on either side. Premature primary closure will subject the patient to increased risk of infection and complications, necessitating repeated OR trips and anesthesia exposure. Depending on the circumstances surrounding the placement of the dressing, timing of the definitive closure can be quite variable. As the risk of compartment syndrome diminishes after an extremity fasciotomy, a delayed primary closure may be indicated. For a large soft tissue defect, serial dressing changes with either wound packing or NPWT may occur over weeks with a more complex definitive treatment required such as grafting or free flap reconstruction. The technique of placement of dermal substitutes and autologous skin grafting is beyond the scope of this chapter. However, prior to placement of autologous graft, the wound must be free of

infection and have healthy granulation tissue, and the host must be optimized for surgery (Fig. 41.4).

Increasing evidence supports closure of contaminated abdominal wounds with placement of a closed vac (i.e., a "skin vac") [19]. Furthermore, Pommerening and colleagues suggest that closure of the skin wound after damage control laparotomy is safe, but does carry a 14.4% risk of SSI

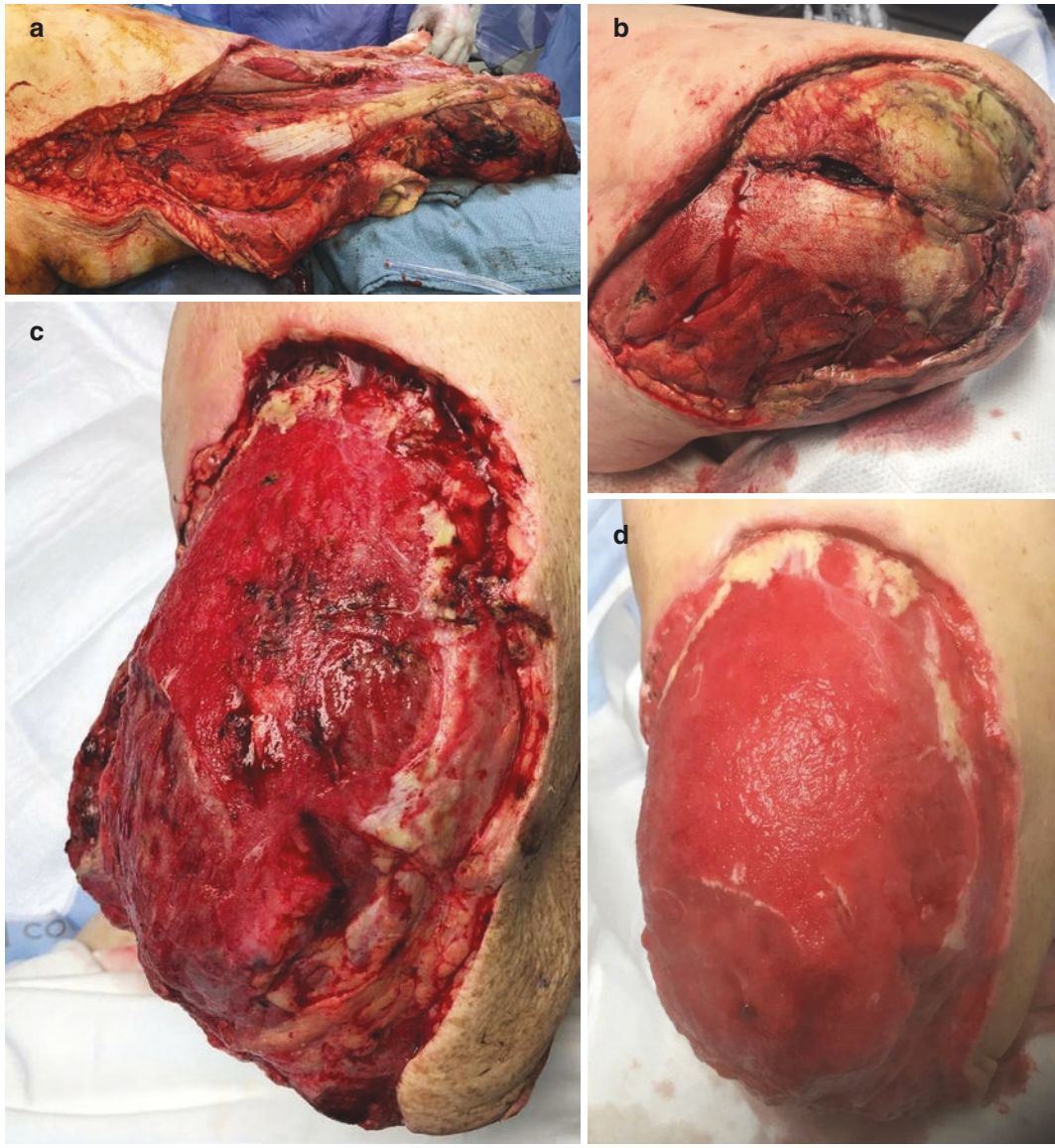

Fig. 41.4 (**a**) Patient significant past medical history of DM, Charcot joint of the foot, HTN, BPH, and right great toe amputation 5 years prior with subsequent forefoot amputation who presented to hospital with non-healing right lower extremity wound. On admission, he was noted to be febrile and tachycardic, with associated leukocytosis, hyponatremia, and hyperkalemia. On physical exam, he was noted with ascending cellulitis to lateral aspect of lower extremity and radiography which included an MRI that revealed probably osteomyelitis of the second and fourth toes and distal aspects of the second and fourth metatarsal bones. POD 0 s/p incision and debridement. (**b**) Right lower extremity, above knee amputation, 3 days after negative pressure vacuum-assisted closure device. (**c**) Right lower extremity AKA 1 week after negative pressure vacuum-assisted closure device. (**d**) Right lower extremity AKA 2 weeks after negative pressure vacuum-assisted closure device. This wound is appropriate for autografting after minimal debridement

[25]. For patients that are not closed and a NPWT or packing is used initially, the patient will be ready for delayed primary closure or permanent closure of the larger deficit using graft or flap.

Wounds that fail to progress to closure through the normal healing process within several weeks are considered chronic wounds. The pathogenesis of failure to heal is thought to be related to aging, repeated ischemic-reperfusion injury, and bacterial colonization [26]. Such wounds require special attention, and involvement of a wound specialist is advised.

Summary

The critical care practitioner can expect to be faced with the management of complex wounds on a regular basis. The team has access to a variety of modalities to care for these wounds, and the management plan should be customized for every patient and every wound individually. Factors to consider include patient comorbidities and current state of illness or injury, wound location and size, amount of contamination, presence or risk of compartment syndrome, and the stage of healing of the wound. The optimal dressing should promote an ideal healing environment and should keep the wound warm, moist, and sterile. The dressing should be durable, cost-effective, and well tolerated by the patient both between and during dressing changes.

Team members who care for patients with complex wounds must become familiar with the indications and contraindications of each modality described above in order to select the right dressing for the patient. They should be familiar with the removal and placement of the dressing and be able to troubleshoot and correct problems swiftly and efficiently. Whether dealing with wet-to-dry dressings, foam dressings, alginates, or NPWT dressing, either on an extremity fasciotomy in a trauma patient or a large soft tissue deficit in an emergency general surgery patient, the provider needs to be comfortable and possess the skills to properly care for these complex wounds to optimize healing and improve the overall hospital course of the patient.

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Escharotomy

42

Christopher K. Craig and Anju B. Saraswat

Introduction

The treatment of burns requires specific training and often requires an experienced burn provider to deliver optimal care. Unfortunately, burn-specific providers are becoming increasingly scarce, and burn centers are becoming increasingly spread out across the country. There are currently 5795 hospitals in the United States [1] – with 490 of those being designated and verified as trauma centers by the American College of Surgeons [2]. Perhaps more alarming to realize is that there are only 70 American Burn Association verified burn centers within the United States [3]. The Residency Review Committee of the Accreditation Council of Graduate Medical Education (ACGME) no longer requires specific burn care training in a general surgery residency. There remains, however, an ACGME requirement to maintain knowledge of burn physiology and initial burn management [4]. There are approximately 240–260 fellows trained in surgical critical care annually [5, 6]. There are approximately 2250 trauma surgeons in the United States [7]. There are approximately seven practicing burn surgeons being trained each year [8], with even their burn-specific training being considered highly variable [9]. There are approximately 300 burn surgeons in the United States [8]. Physician assistants (PAs) and nurse practitioners (NPs) are often "filling the gap" by assuming an increasing presence in the "direct care of the patient," [10] yet they too receive inconsistent exposure to burn care curricula, if any at all, during their training.

In the United States, over one million people sustain burns serious enough to warrant attention from a healthcare provider. This results in approximately 450,000 ED visits, clinic visits, and hospital admissions per year with a mortality of nearly 3300 patients dying annually [11]. A majority of burn-injured patients are initially managed by community hospitals or regional trauma centers – some with more severe injuries than others – prior to being transferred to a burn center for definitive care [12]. The quality of burn care is often measured by long-term functional outcomes and appearances – not merely survival [13]. It is therefore critical to refer patients to a burn center as soon as possible after initial assessment and stabilization at an outside facility.

Initial stabilization of the burn-injured patient should always begin with assessment and maintenance of the airway, breathing, and circulation [13]. Burns with a total body surface area > 20% TBSA should also undergo a formal fluid resuscitation following the Parkland formula (or another consensus formula as prescribed by your local burn center) [13]. Tetanus prophylaxis should be

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provided if the patient has not been previously immunized within the last 5 years [13]. Gastric decompression with an NG tube is often performed at the outside hospital prior to transport, especially when a patient requires endotracheal intubation for airway stabilization or if the patient is being transported by air ambulance [13]. Pain control should be achieved with intravenous medication administration, as subcutaneous and intramuscular injections can demonstrate variable absorption due to cutaneous injury and prove less reliable [13]. Specific evaluation of the burn severity (size, depth, location, and circumferential nature) should occur immediately. Distal neurocirculatory function for all extremities should occur, especially if circumferential or near-circumferential burns have occurred. Ventilatory and respiratory status should also be assessed with specific attention given to circumferential burns to the torso resulting in ventilatory compromise. Thoracic and/or extremity escharotomies may be emergently indicated.

Indications

Escharotomy is indicated when circumferential or near-circumferential deep partial-thickness or full-thickness burns of the extremities or thorax create a tourniquet affect resulting in circulatory or respiratory compromise (i.e., compartment syndrome).

Limbs

Full-thickness burn injury to the extremities can result in neurovascular compromise that cannot otherwise be alleviated by simple elevation of the affected limb [14]. The leathery eschar, which is pathognomonic of full-thickness injury, can cause a tourniquet effect by way of its inflexibility combined with capillary leak and resultant third space fluid formation beneath the unforgiving burned skin. The assessment of circumferential extremity burns should include the identification of pain, pallor (pale skin), paresthesia (numbness/tingling), pulselessness, and paralysis (weakness). Identification of these signs and symptoms in a circumferentially burned extremity is considered an emergency, and immediate discussion should take place to determine if an escharotomy is necessary (typically by a surgeon) prior to transfer.

Thorax

If circumferential burns to the torso exist, and there is compromise of ventilation caused by chest wall inelasticity resulting from chest wall and/or abdominal wall full-thickness injury, then escharotomy should be considered [13]. Of note, non-circumferential burns may also result in a similar restriction of chest wall mobility and require escharotomy. Abdominal escharotomy may also be required if diaphragmatic movement is restricted. This is most often seen in pediatric patients under 12 months, as they predominately breathe with their diaphragm. The assessment of thoracic burns should include the identification of restricted movement of the chest wall (and/or abdominal wall), decreased respiratory effort, decreased ventilation due to shallow breathing and reduced air entry bilaterally, tachypnea, hypoxemia, and generally compromised respiratory function that correlates with chest wall or abdominal wall burn injury and breathing patterns. Identification of these signs and symptoms in a circumferentially burned or severe anteriorly burned chest/abdominal wall is considered an emergency, and immediate discussion should take place to determine if an escharotomy is necessary (typically by a surgeon) prior to transfer.

Contraindications

There are no true contraindications to performing escharotomies in patients determined to need them, due to the loss of life or limb that would occur if an escharotomy was not performed. It should, however, be noted that escharotomy is not indicated in superficial or partial-thickness burn injuries that would not otherwise require surgical excision and grafting, have maintained

elasticity of the skin, and have not resulted in loss of pulse (extremities) or directly resulted in respiratory compromise (thorax).

Risks/Benefits

Common risks associated with the performance of escharotomies include, but are not limited to:

1. Damage to the ulnar nerve when escharotomies are performed at the level of the elbow.
2. Damage to the common peroneal nerve when escharotomies are performed at the level of the knee.
3. Inadequate escharotomies being performed when special care is not taken to make adequate incisions that transect all dermal bands along the incision line.
4. Excessive blood loss when care is not taken to properly control hemorrhage via diathermy, pressure, or ligatures when necessary.
5. Unintentional breach of the fascia when incisions are made too deeply.
6. Generically speaking, there is risk of damaging surrounding tissue, as it is often necessary to extend escharotomy incisions through burned tissue until healthy viable tissue is reached.
7. Bacteremia may result when underlying tissue is infected (rare).
8. Infection of the escharotomy wounds (rare).

The benefit of escharotomy is clear – as it is an emergent procedure meant to salvage life and/or limb in face of a full-thickness burn injury that compromises circulation or ventilation in the severely burn-injured patient. The consequence of not performing an escharotomy when indicated is severe:

1. Compartment syndrome resulting in muscle necrosis
2. Permanent nerve damage/injury
3. Gangrene resulting in amputation of the affected limb
4. Respiratory compromise and inadequate ventilation in torso burns
5. Abdominal compartment syndrome due to visceral hypoperfusion
6. Severe myoglobinuria
7. Renal failure
8. Hyperkalemia
9. Severe metabolic acidosis
10. Inadequate or poor response to standardized fluid resuscitation protocols

It should be noted that in patients who have clearly established "fourth degree" burns or a delay in care where irreversible mummification of the limb has occurred, the risk and potential complications of performing a surgical escharotomy should be weighed carefully against any potential benefits. These patients may likely require amputation if the limb is determined to be otherwise unsalvageable.

Preparation

Equipment

- Sterile or clean drapes.
- Povidone-iodine solution.
- Electrocautery (preferred) or scalpel.
- Suture and needle driver for possible vessel ligation.
- Silvadene/gauze dressings for application to hemostatic wound following the procedure.
- Appropriate IV sedation and IV pain medications.
- Typically, general anesthesia is not required in adult populations; however, it should be considered in pediatric patients.

Personnel

In general terms, an escharotomy should be performed by the most experienced provider present. Ideally, this would be a plastic or burn surgeon, trauma surgeon, general surgeon, an experienced emergency medicine physician, or an experienced advanced practice provider (APP) such as a physician assistant or nurse practitioner. Appropriate advice and discussion should always

take place with the burn specialist that serves your catchment area.

- Surgeon, emergency physician, or APP who has been properly trained in escharotomy techniques.
- Nurse or first-assist to help with maintaining positioning of limb during procedure.
- Nurse to assist with administration of sedation and pain medications.
- If anesthesia is required, it should be achieved and monitored by a second provider who has been properly trained in anesthesia (e.g., anesthesiologist or CRNA).

Positioning

- Patient should be positioning supine in the center of the bed or operative table.
- The upper extremities should be placed in an anatomically neutral position (forearms should be supinated), with arms extended out to the sides (imagine Da Vinci's Vitruvian Man)
- The lower extremities should be extended straight, allowing easy access to the lateral and medial aspects of each leg.
- The torso should be centered on the bed, allowing easy access to the left and right mid-axillary lines.

Procedure

- Once proper positioning is achieved, the patient should be prepped with povidone-iodine solution and draped in the usual manner. While this is not a sterile procedure, care should be taken to minimize contamination of the wound via proper prepping and draping techniques.
- Draw a line along the medial and lateral aspects of the affected limbs and/or along the mid-axillary lines of the torso (Fig. 42.1). A line should also be drawn transversely across the superior chest at the level of the clavicles and transversely across the inferior chest just below the costal margin, thereby connecting the vertical lines previously drawn mid-axillary lines (Fig. 42.1).

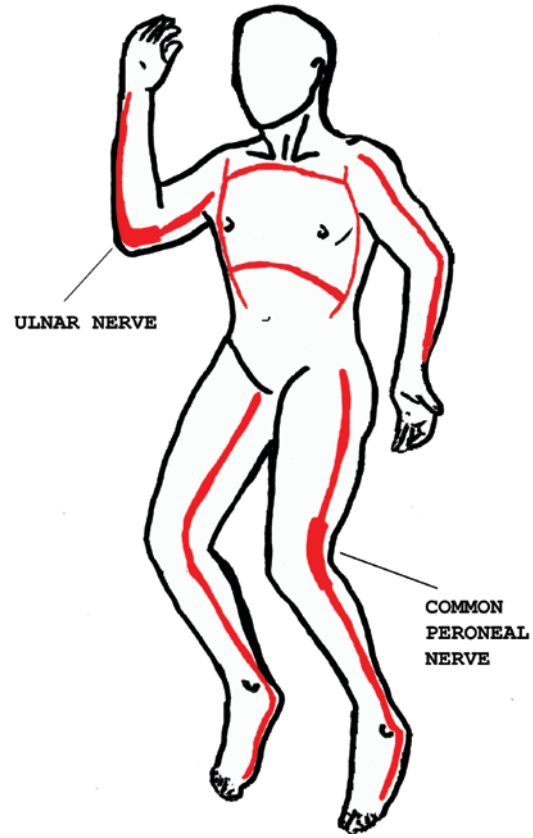

Fig. 42.1 Escharotomy diagram. (Courtesy of Craig CK, Holmes JH. Winston Salem, NC: Wake Forest University School of Medicine © 2020)

- Preferably using an electrocautery knife, use the coagulation feature to cut along the lines drawn above. A scalpel may be used if electrocautery is not available; however, this may result in increased bleeding.
  - Ensure that all incision penetrate throught the epidermis and dermis, such that fat is visible. Muscle and fascia should not be seen at the base of the wound if the proceduralist has properly cut at "skin depth" as indicated.
  - Adequate release should be obtained, with no dermal bands remaining. The proceduralist should run his or her finger along the incision line, feeling for tight bands and cutting them when found.

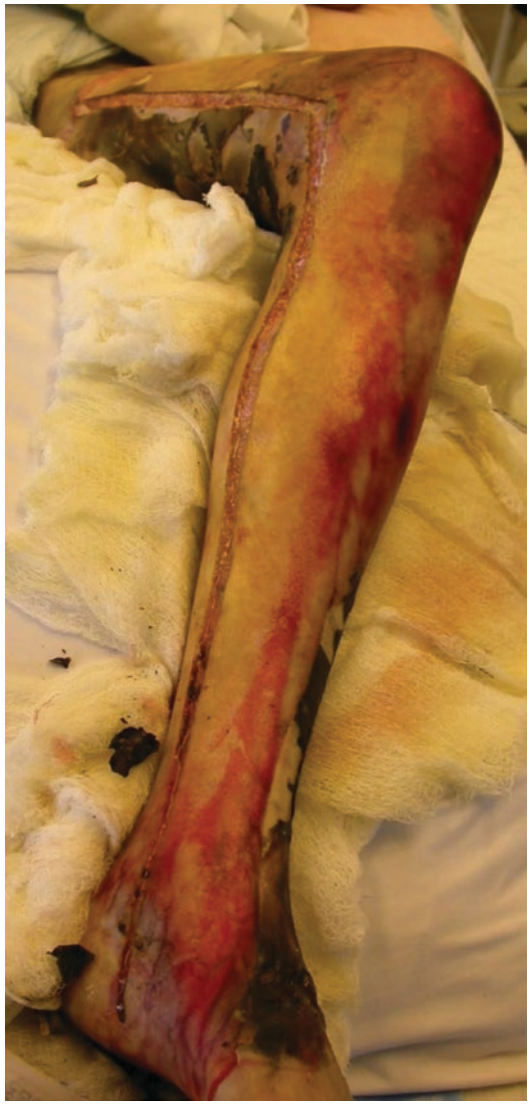

Fig. 42.2 Escharotomy of left lower extremity. (Courtesy of Craig CK, Holmes JH. Winston Salem, NC: Wake Forest University School of Medicine © 2009)

- Incision lines should be extended approximately 1–2 cm proximal and distal to the burn in such a manner that the escharotomy extends from "good skin to good skin" or "good skin to air" if the burn extends all the way to the end of the extremity (Fig. 42.2).
- Special care should be taken when incisions are extended across joints, to avoid damage to the neurovascular structures that lie superficially near the elbows, wrists, knees, and ankles, respectively.
- Hemostasis should be achieved with electrocautery, pressure, or ligature of vessels as necessary.
- Once hemostasis is achieved:
  - If transferring the patient from your facility to a burn center, the wounds should be covered with clean and dry dressings.
  - If the patient must remain in your care prior to transfer (e.g., disaster situation, weather preventing immediate transfer, or other significant delays in transport), the wounds should be dressed with silver sulfadiazine (SSD) or a similar medication applied to the incision line and over the surrounding burn. A secondary gauze dressing should be applied to cover all wounds. A tertiary elastic bandage or elastic netting may be used to hold the gauze dressings in place.
- Holes should be cut in the dressings near the radial artery, ulnar artery, dorsalis pedis, and/or the posterior tibialis, so proper monitoring of circulation in the limbs can be easily achieved with monitoring of Doppler signals and palpation of pulses.
- Limbs should be elevated above the level of the heart.
- Breathing and ventilation should be closely monitored when the chest wall is involved.
- Continued burn care should be provided until successful transfer to a burn center can occur.
- **Of note, if proper escharotomies are performed and the patient continues to demonstrate signs of compartment syndrome, fasciotomy may be indicated. While this is certainly possible, it is rare and should only be performed when truly necessary. Always consider inadequate escharotomy before assuming a fasciotomy is needed.

Complications

Despite the complications associated with inadequate decompression of circumferential full-thickness burn wounds, there have been reports

of inadequate procedural performance [15]. Wounds should be monitored immediately upon arrival and then regularly thereafter. Following the performance of an escharotomy, the proceduralist should specifically look for continued bleeding from the incision site and monitor for signs of inadequate decompression (e.g., signs of distal ischemia in the extremities or poor ventilation when the torso is involved). Patient may also show evidence of damage to the ulnar nerve or common peroneal nerve due to its proximity to the necessary incision lines that cross the elbow or knee, respectively. Given the full-thickness nature of the wounds requiring escharotomy, eventual excision and grafting is inevitable. Escharotomy, however, can sometimes require surgical reconstruction.

Keys to Success, Perils, and Pitfalls

- Always extend the incision line at least 1–2 cm into good skin. If the burn pattern is such that "good skin" is not present distally or proximally, then the incisions for the upper limbs should extend from the axilla (medially) and shoulder (laterally) to the level of the thenar and hypothenar eminences. Likewise, the incision for the lower extremities should extend from the groin (medially) and iliac crest (laterally) to the level of the great toe and fifth toe.
- Superficial veins and capillary beds will certainly be disrupted. Adequate hemostasis should be obtained with electrocautery or ligation prior to dressing the wounds.
- Dermal bands must be transected for an escharotomy to be successful. Leaving these unincised can be as bad as not performing an escharotomy at all.
- Escharotomy of the digits and toes is rarely beneficial and usually does not result in any increased functional outcome. Surgical management of these areas should be reserved for the practitioner with the most experience as the risk of damaging neurovascular bundles leading to permanent loss of function is significant.

CPT Coding

- 16035 – Escharotomy, initial incision
- +16036 – Escharotomy, each additional incision

Be sure to clearly document each incision made in your procedure note. It is advisable to very specifically list "Escharotomy Incision #1, Escharotomy Incision #2, etc." until all incisions are properly listed to maximize proper billing/coding and appropriate reimbursement.

Summary

Burn patients require rapid and thorough evaluation. A formal fluid resuscitation should be initiated for burn injuries exceeding 20% total body surface area (TBSA). Burn patients with circumferential extremity or torso burns are at risk of losing life or limb. Emergent decompression of these burns is necessary and best achieved via properly placed escharotomy incision(s). Without proper decompression, burn patients may experience tissue ischemia, tissue necrosis, nerve damage, loss of limb, respiratory compromise, or death from organ failure or respiratory failure. Ongoing serial examination of burn-injured patients, with circumferential or near-circumferential burns, is critical. At the earliest sign of compromise, the patient should undergo escharotomy by the most qualified provider available. Reassessment of the affected burn-injured area(s) is also important, as you monitor to see that your intervention was beneficial. Such assessments should include obtaining Doppler signals, performing a physical examination on the patient, and specifically testing for the presence of palpable pulses. Transfer to a verified burn center should occur as rapidly as possible.

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Additional Resources

http://ameriburn.org/education/abls-program/

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Part IX

Ultrasonography in the ICU

43 Extended Focused Assessment with Sonography in Trauma (eFAST)

Janna S. Landsperger and Muneer Bhatt

Introduction

In emergency settings it is imperative to have well-arranged processes with clear protocols to assess a patient quickly and effectively. The use of point of care ultrasonography is an important bedside tool to assess and guide the management of critically ill patients.

The *extended focused assessment with sonography in trauma* (eFAST) is a rapid bedside ultrasound exam, performed by clinicians, which allows clinicians to accurately detect fluid in the peritoneal and pleural cavities and air in the pleural cavity. The indications for eFAST are:

1. Blunt trauma
2. Penetrating trauma
3. Unexplained hypotension
4. Altered mental status

The aim of eFAST is to identify free fluid and air and to correlate the ultrasound finding with the patient status (Fig. 43.1) [1]. It commonly has six views (Fig. 43.2).

Diagnostic performance of eFAST has excellent sensitivity and specificity for identification of free fluid in patients (sensitivity 64–96%, specificity 86–99%) and is highly accurate for identification of pneumothorax (sensitivity 77–95%, specificity 99%) [2].

The most effective use of eFAST has been rapid triage of hemodynamically unstable patients leading to reduced time to appropriate intervention, shortened hospital stays, and lower hospital costs [3].

Integrating ultrasound training into the medical education of advanced practice providers can be done through a sequence of formal didactic lectures, hands-on teaching, and skills validation assessment (Fig. 43.3). Periodic ongoing assessments are essential to assure operators maintain quality performance. Research has shown that advanced practice providers trained in ultrasound are able to perform point of care ultrasound with a high degree of accuracy [4].

Basic Ultrasound Physics

The first step in learning to use ultrasound is to have a basic understanding of how medical ultrasound works.

Ultrasound is made up of mechanical waves that can transmit through different materials such as fluids, soft tissues, and solids. Medical ultrasound machines generate ultrasound waves and receive the reflected echoes. To obtain the image, electricity is applied across the crystals in the

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D. A. Taylor et al. (eds.), *Interventional Critical Care*, https://doi.org/10.1007/978-3-030-64661-5_43

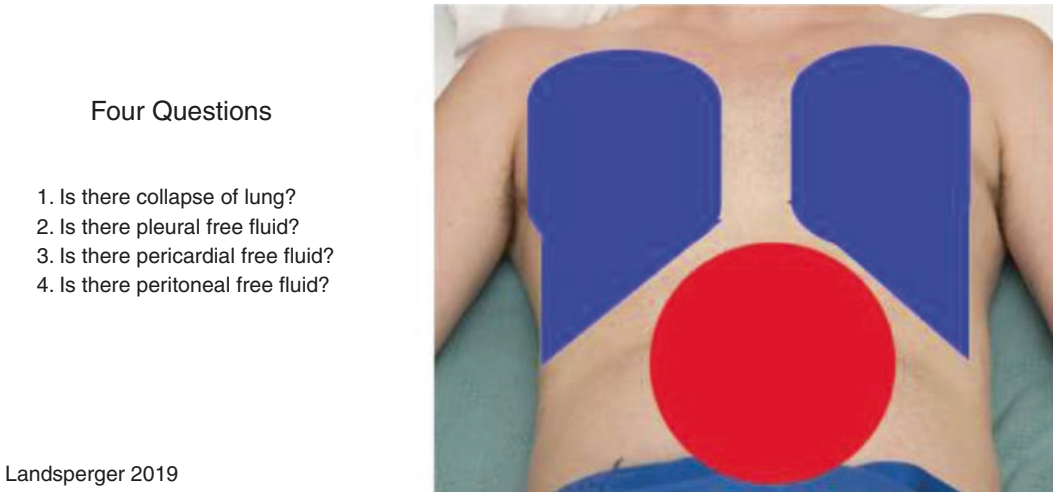

Fig. 43.1 Aim of eFAST

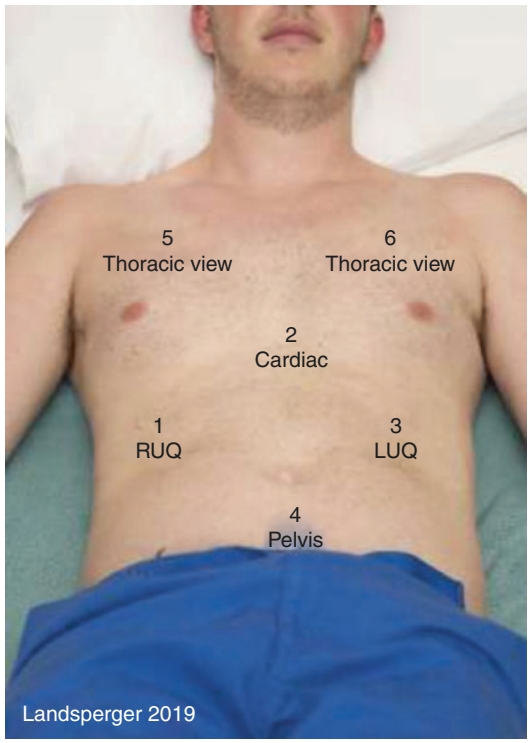

Fig. 43.2 Views obtained for eFAST

transducer causing them to vibrate and emit ultrasound waves [1].

As ultrasound waves pass through various body tissues, they are reflected back to the transducer creating an image on the ultrasound screen

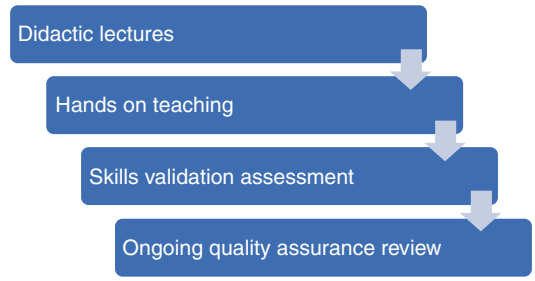

Fig. 43.3 Key components to ultrasound training

[1] (Fig. 43.3). Because ultrasound sound waves have a difficult time traveling through the air, ultrasound gel is used to reduce the air between your patient and the transducer to reduce acoustic impedance and reflection to allow for a clear image to be produced (Fig. 43.4).

Interpreting Tissue Echogenicity

Echogenicity of the tissue refers to the ability to reflect or transmit ultrasound waves in the context of surrounding tissues. Whenever there is an interface of structures with different echogenicities, a visible difference in contrast will be apparent on the screen [5]. When an ultrasound beam passes through tissue without significant reflection, this area appears black or anechoic on the images. Simple fluid is anechoic. When a wave is

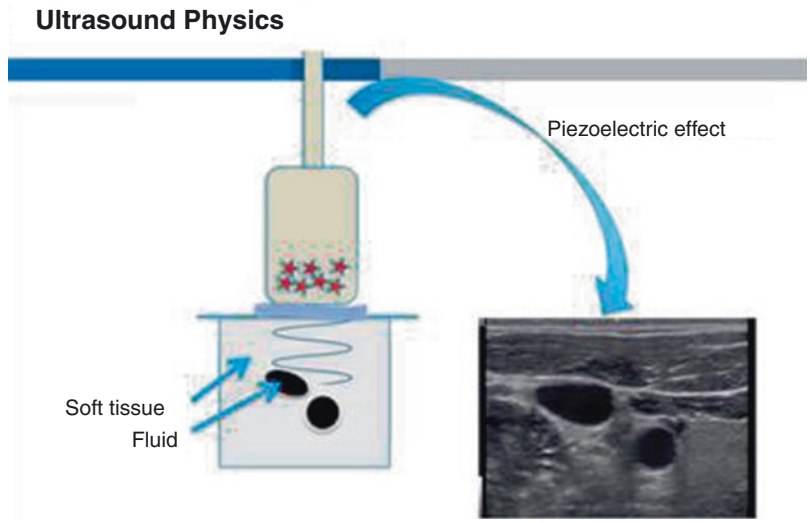

Fig. 43.4 Ultrasound physics. The ultrasound transducer detects the returning sound wave and transforms it into an electric signal (piezoelectric effect). The signal is then processed and then displayed as an image on the screen. (Image courtesy of Amy Morris, MD)

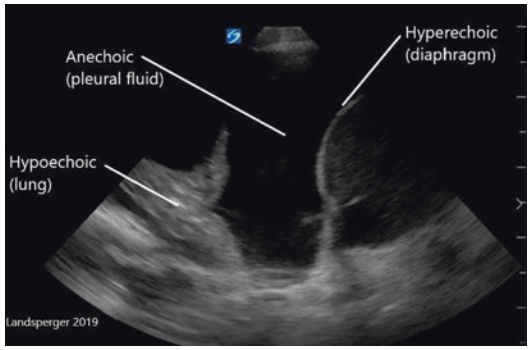

Fig. 43.5 Based on echogenicity, a structure can be characterized as hyperechoic (white on the screen), hypoechoic (gray on the screen), and anechoic (black on the screen)

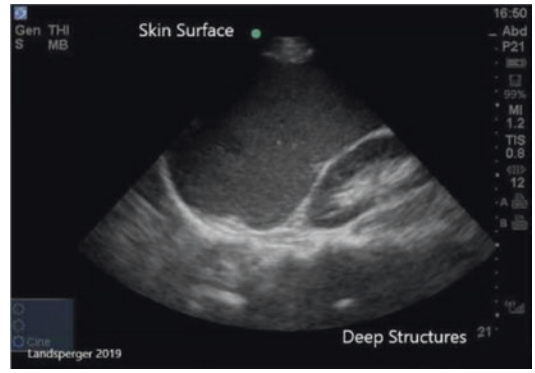

Fig. 43.6 The top of the screen represents the skin tissue; the bottom of the screen represents the deepest part of the tissue

almost entirely reflected back to the transducer, due to a tissue interface with a large difference in acoustic impedance, the structure appears white, or hyperechoic. Examples of hyperechoic structures include the bone, gallstones, diaphragm, and pericardium. Soft tissue causing partial beam reflection appear hypoechoic or various shades of gray (Fig. 43.5).

Image Orientation

One initial challenge in ultrasound image interpretation is understanding the orientation of the image on the screen. The top of the screen represents the most superficial part of the tissue you are scanning, or the skin surface. The bottom of the screen represents the deepest part of the tissue [6] (Fig. 43.6).

To differentiate between left and right on the ultrasound screen, attention must be paid to how you hold the transducer. Each transducer has an indicator on one side such as a groove or a raised dot. The indicator corresponds to the orientation mark on the ultrasound image.

You can use the orientation mark to orient yourself to an image on the screen. For example, to differentiate left and right, if the operators hold the transducer with the indicator pointing to the patient's left side, the orientation dot would appear in the upper left screen (Fig. 43.7).

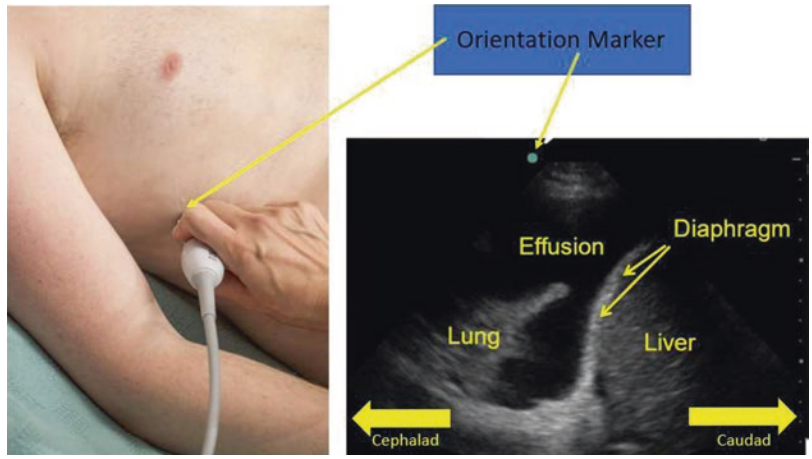

Fig. 43.7 Indicator on transducer corresponds to the orientation marker on the ultrasound. In this image of a pleural effusion, the indicator is cephalad and the orientation marker is on the left

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For other exams, instead of using left and right, you will use a cephalad or caudad orientation. If the transducer indicator is pointing toward the patient's head (caudad), the orientation marker will appear on the left side of the screen [7].

Ultrasound Transducers

Choosing the appropriate transducer is the first step to acquiring a good ultrasound image.

The frequency of waves emitted by the transducer has a direct relationship to the sharpness of the images it produces and an inverse relationship with a depth of penetration. The lower the frequency is, the poorer the image resolution, but the greater the depth of wave penetration. Higher-frequency probes have less depth penetration but have the advantage of higher resolution [1].

The linear array transducer has a high frequency (6–13 MHz) and reaches a maximum depth of penetration of 6 cm. It produces a detailed, rectangular-shaped image which is ideal for superficial applications like vascular imaging or scanning for pneumothorax (Fig. 43.8).

The phased array and curvilinear transducers have a frequency of 1–5 mHz with deeper maximum depth of up to 35 cm and a small square footprint. It shows a wedge-shaped image and is ideal for imaging deeper structures [6] (Fig. 43.9).

Positioning

Learning proper ergonomics is imperative for the new operator. When performing eFAST, the ultrasound machine should be positioned on the side of the patient, near the operator. In order for the operator to optimize the image quality, the ultrasound should be positioned in a way that the operator can hold the transducer with their dominant hand and easily reach the ultrasound machine with their non-dominant hand to adjust the depth and gain of the images (Fig. 43.10).

When performing eFAST, the patient should be lying semi-recumbent, supine, or in Trendelenburg. The transducer should be held gently and quite low on the probe, close to the scanning surface. The operator's hand should rest on the patient's body in order to stabilize the transducer. Remember to dim ambient lights to improve the image quality on the screen (Fig. 43.11).

Knobology

Depth

Based on what transducer you choose, the depth of field can be adjusted to best visualize the structures of interest. The depth of the structure appears on the right side of the ultrasound image.

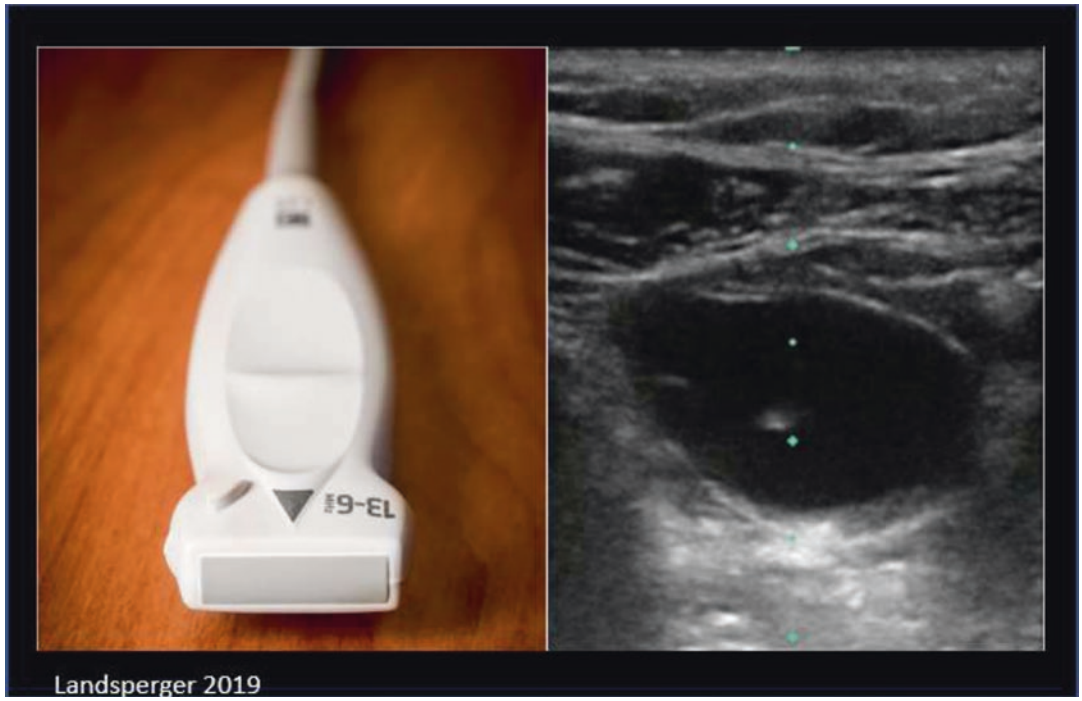

Fig. 43.8 The linear array transducer, commonly used for vascular imaging or scanning for pneumothorax

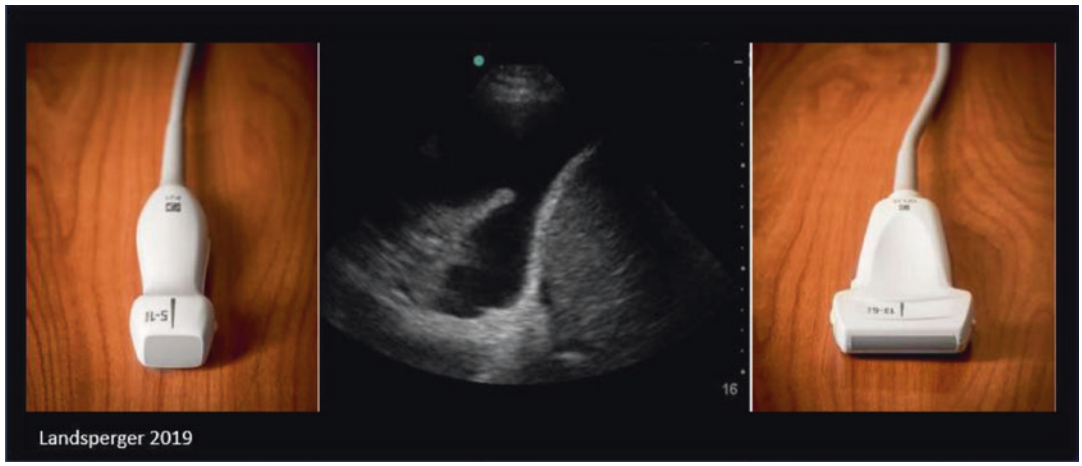

Fig. 43.9 The phased array and curvilinear transducers are ideal for imaging deeper structures

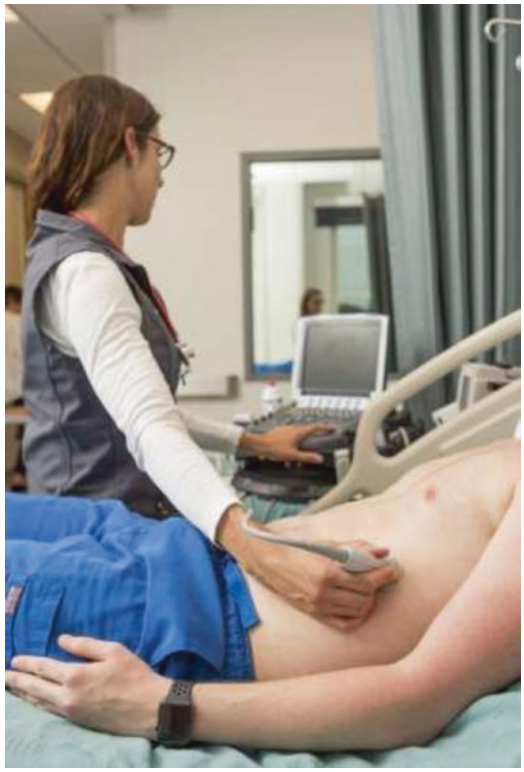

Fig. 43.10 Ultrasound ergonomics. Proper positioning is key to good image acquisition

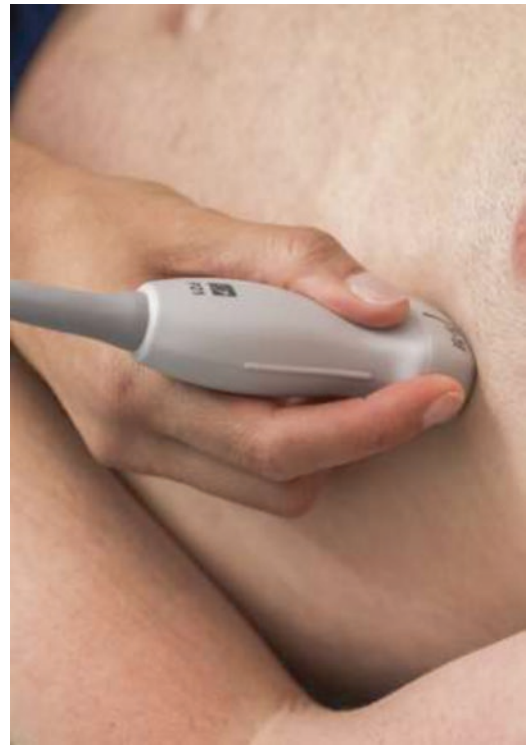

Fig. 43.11 To stabilize the transducer, the operator's hand must rest on the patient's body

It is wise to begin with a somewhat higher depth setting in order to first get a "big picture" and then gradually decrease the depth when the targeted structure is found [5] (Fig. 43.12).

Gain

Gain is the degree of amplification applied to signals returning to the transducer. It can be thought of as brightness control. High gain is brighter; low gain is darker. Changing the gain will change the amount of white, black, and gray on the monitor. Adjusting the gain of the image may improve the operator's ability to distinguish structures on the screen. Most ultrasound machines have an auto-gain knob, which is commonly used to receive an optimal image [7] (Fig. 43.13).

Mode Buttons

Brightness mode (*B Mode*) is the basic mode that is generally used. B mode gives a two-dimensional (2D) black and white image. *M-Mode* shows motion over time of structures seen in a stable axis. A vertical line is placed through the structure of interest.

The machine then converts ultrasound echoes measured at this line onto the vertical axis of a graph with time on the horizontal axis.

Color Doppler is used to identify and enhance blood flow. Blood vessels have a distinct appearance on color Doppler mode: flow toward the probe appears red, while flow away from the probe appears blue. A useful mnemonic used by radiologists is BART, i.e., Blue Away, Red Toward [6] (Fig. 43.14).

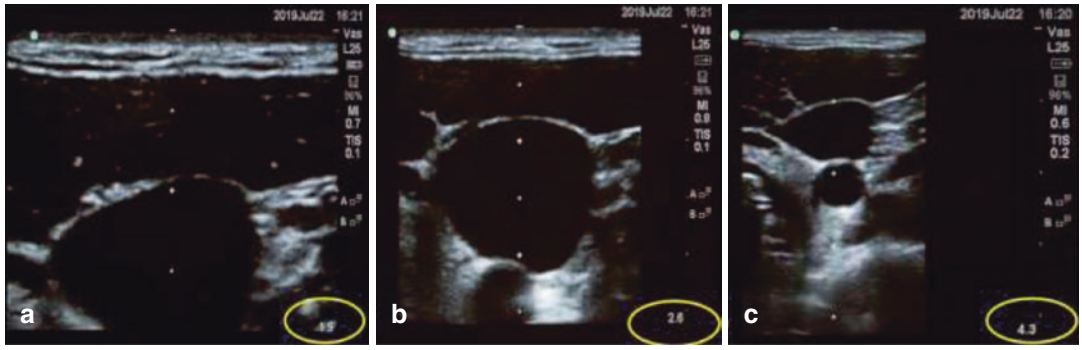

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Fig. 43.12 Setting the appropriate depth of the structure is important. Image A shows the intrajugular vein at a depth of 1.9 cm. This shallow depth prevents the operator's ability to view the carotid artery. Image B shows the intrajugular vein at a depth of 2.6 cm; the operator is easily able to identify the carotid artery. Image C shows the intrajugular vein at a depth of 4.3 cm. This depth allows the operator to identify the carotid; however it may be too deep to easily identify shallow structures

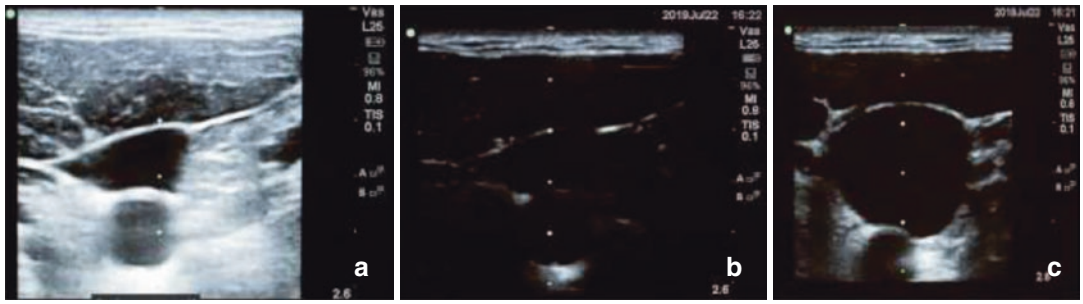

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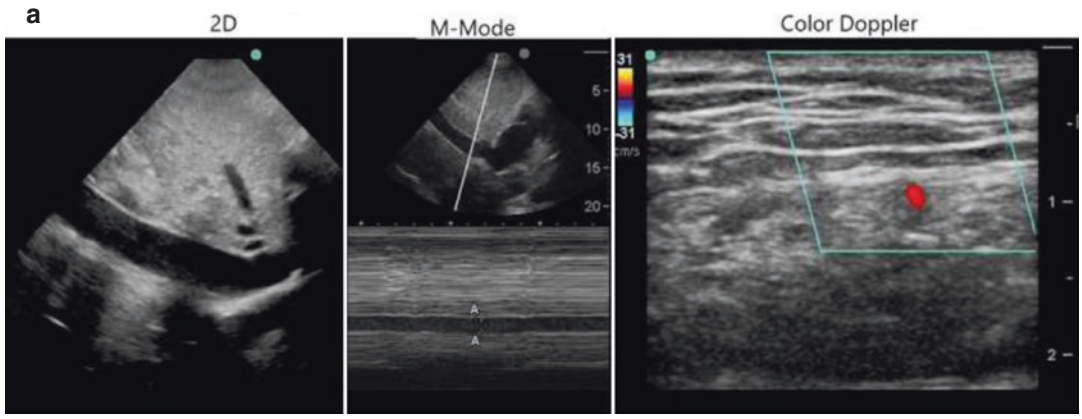
Fig. 43.13 Setting the appropriate gain of the structure is important. Image **a** shows the intrajugular vein that has high gain, or is over gained. Image **b** shows the intrajugular vein that has low gain, or is under gained. Image **c** shows the intrajugular vein at ideal gain

Ultrasound Artifacts

Ultrasound artifacts are images that do not accurately depict the tissue being scanned. This includes images that are seen that are not present, tissue structures which are present that are not seen by ultrasound, or images showing tissues or structures with incorrect location and size. When performing ultrasound, the operator should be knowledgeable of the sonographic artifacts that can be misleading or serve as a diagnostic aid.

Several types of artifacts can be seen on B-Mode. *Acoustic shadowing* occurs when sound cannot pass through an impermeable or almost impermeable tissue such as the bone or a calcified structure (Fig. 43.15). *Reverberation* occurs when sound bounces between two greatly reflective structures causing sound to reverberate over and over, creating a line of sound down the image screen. A-lines and B-lines are examples of reverberation (Fig. 43.16). *Acoustic enhancement* occurs when a sound passes through a fluid-



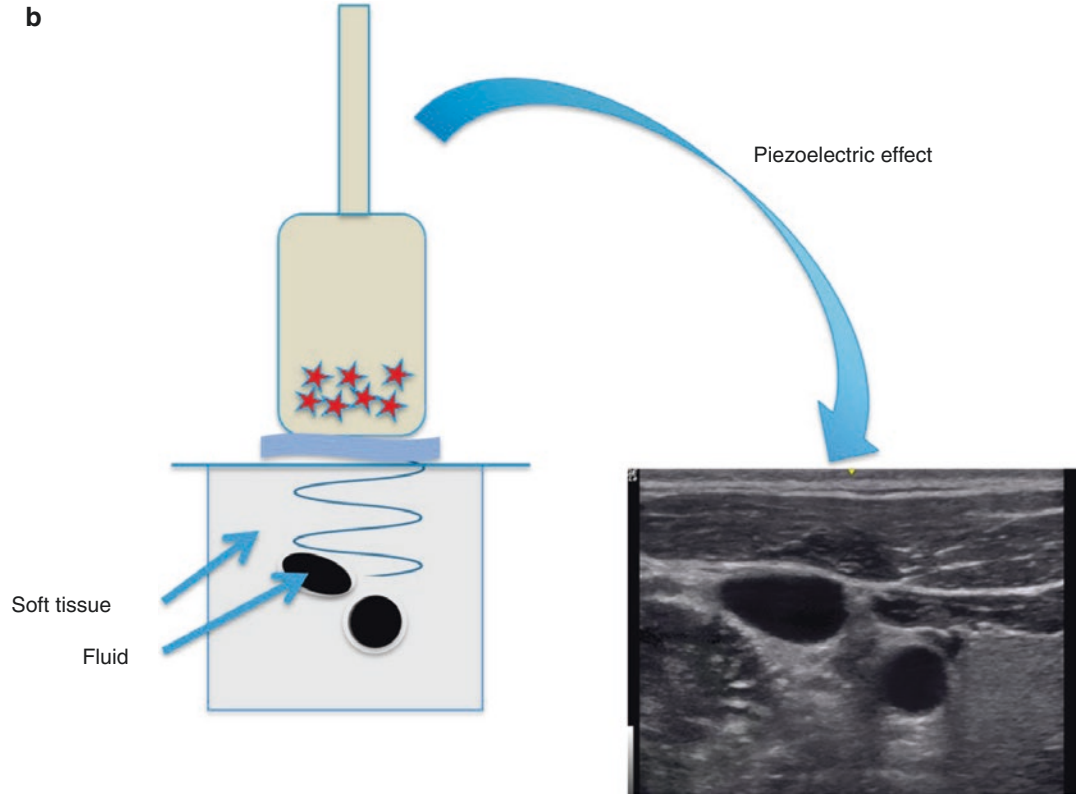


Fig. 43.14 The 2D or brightness mode is the basic mode. M-Mode shows motion over time of structures seen in a stable axis. Color Doppler is used to identify blood flow

filled structure, without significant attenuation causing an increase in acoustic energy. This results in structures posterior to the fluid-filled structure appearing brighter or more echogenic. Common examples include simple cysts, the gallbladder, the bladder, or large vessels (Fig. 43.17). *Mirror image artifact* is rare but striking and occurs most often when scanning tissue close to the pericardium or diaphragm. When ultrasound waves hit a highly reflective structure, such as the diaphragm, the machine can interpret the images as coming back twice, resembling a mirror image [8] (Fig. 43.18).

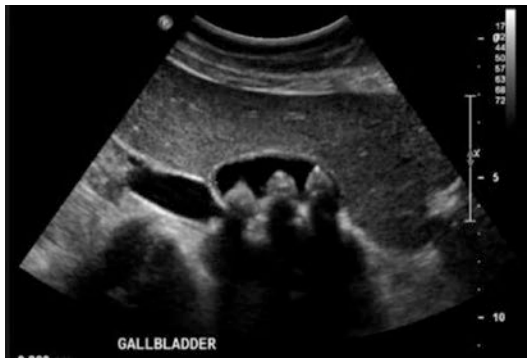


Fig. 43.15 Acoustic shadowing. Loss of signal deep to the gallstone

Image Acquisition: eFAST

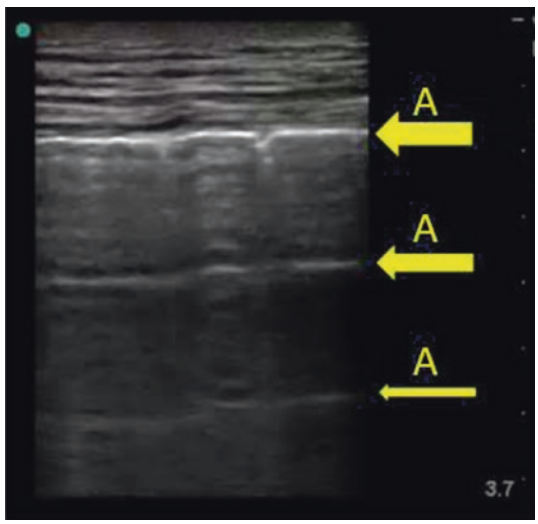
Abdominal Views

Perihepatic

The main objective of performing eFAST is to detect blood in the areas where it should not exist. Begin with the right upper quadrant or perihepatic view. The perihepatic view allows the clinician to view the liver, right kidney, and subphrenic space.

Technique [1]

1. Use the phased array probe and point the indicator cephalad.
2. The patient should be lying supine.
3. Place the probe in the mid-axillary line between the 8th and 11th rib to find the liver.



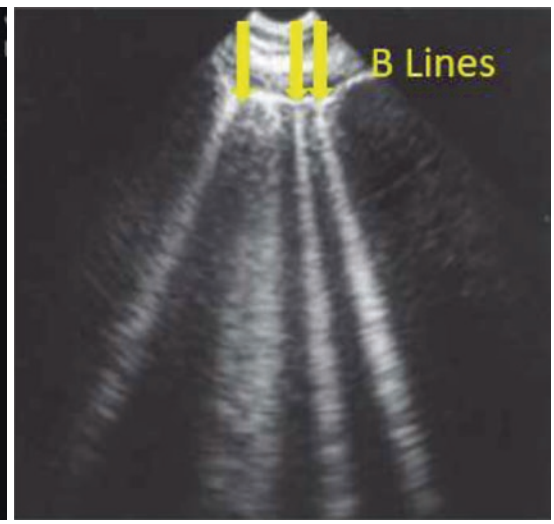


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Fig. 43.16 (**a**) A-lines represent reverberation (**b**) B-lines represent reverberation artifact

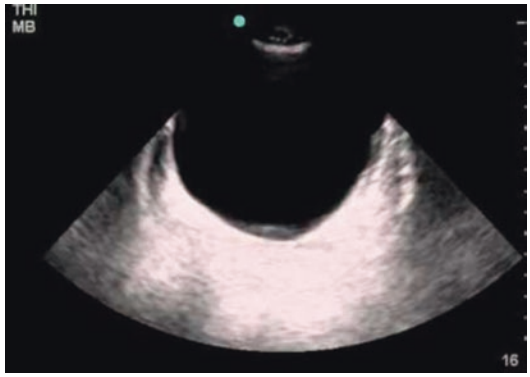

Fig. 43.17 Acoustic enhancement. Structures posterior to fluid-filled structure appear more echogenic

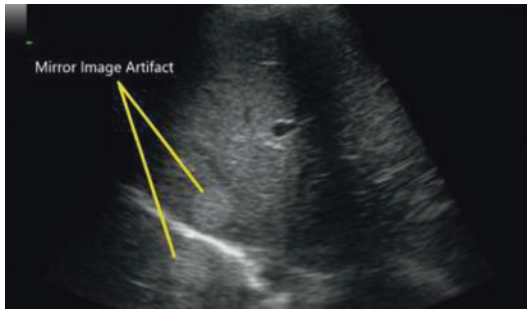

Fig. 43.18 Mirror image artifact, when ultrasound waves hit a highly reflective structure, the machine can interpret the images as coming back twice, resembling a mirror image

4. Angle the probe until the hepatorenal recess (Morison's pouch) is seen. In a normal view, the liver and right kidney are closely aligned separated by a brightly echogenic surface.
5. After evaluating the hepatorenal recess, look above the liver at the liver-diaphragm interface, then look just above the diaphragm to evaluate for pleural effusion or hemothorax (Fig. 43.19)

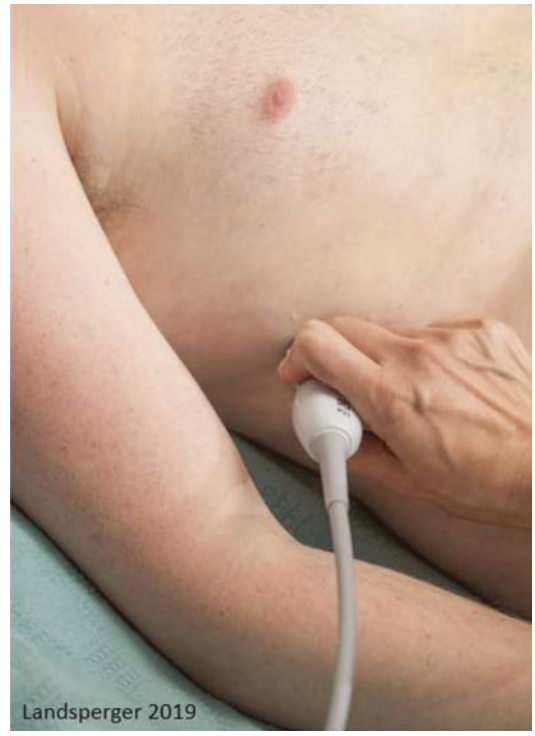

Fig. 43.19 RUQ image acquisition

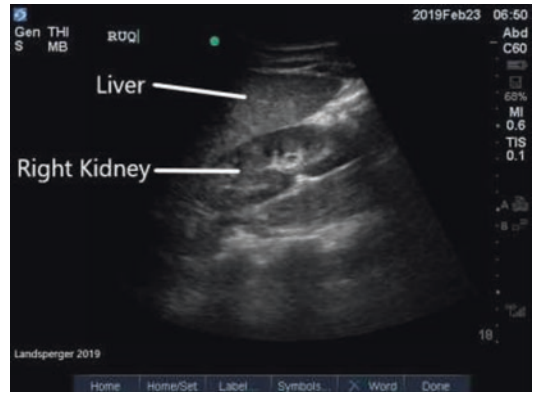

Fig. 43.20 Normal RUQ view, no free fluid present

Normal Anatomy

When interpreting the ultrasound image, a negative exam has no free fluid. The provider will be able to successfully identify the liver, right kidney, hepatorenal recess, and subphrenic space [1] (Fig. 43.20).

Abnormal Findings

When interpreting the ultrasound image, a positive exam has free fluid. Fluid will collect in the hepatorenal recess and/or above the liver (between liver and diaphragm). If free fluid is

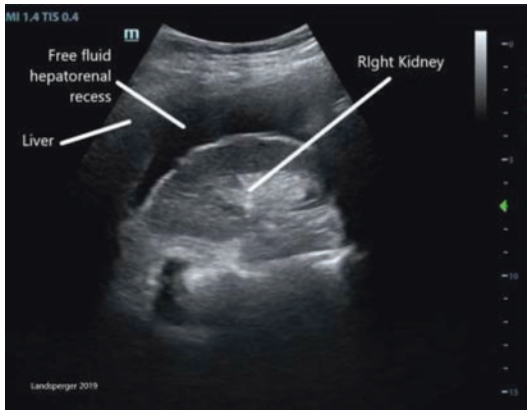

Fig. 43.21 Abnormal RUQ view, free fluid present in hepatorenal recess (appears as a black line)

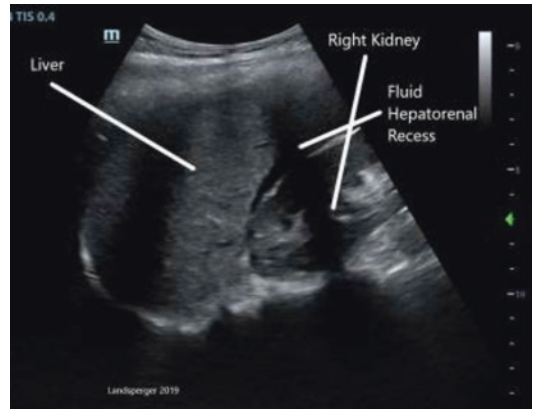

Fig. 43.22 Free fluid in hepatorenal recess secondary to renal artery laceration

present in the abdomen, it will appear as a black, anechoic line between the liver and right kidney. A pleural effusion or hemothorax will appear as a black, anechoic line or triangle just above the diaphragm [6] (Fig. 43.21).

Case-Based Learning: Free Fluid in Hepatorenal Recess

A 42-year-old female presents to the emergency department following a motor vehicle crash. She was an unrestrained driver in a rollover motor vehicle crash with ejection. On arrival to the emergency department, patient complained of severe right-sided abdominal pain as well as left-sided hip pain. GCS 14, afebrile, HR 103, BP 112/72, SpO_2 100% on 100% non-rebreather. Exam notable for diffuse abdominal tenderness. Labs notable for hemoglobin 6, hematocrit 20. eFAST was performed and was positive showing free fluid in the hepatorenal recess as well as large volume hemoperitoneum. CT was performed and showed an unstable left pelvis fracture as well as a right renal artery laceration. Patient was transfused with packed red blood cells. She underwent urgent embolization of right renal artery as well as operative repair of pelvis fracture (Fig. 43.22).

Perisplenic

The perisplenic view allows the clinician to view the spleen, left kidney, and subphrenic space.

Technique [1]

1. Use the phased array probe and point the indicator cephalad.
2. The patient should be lying supine.
3. Place the probe in the posterior-axillary line between the fifth and ninth rib to find the spleen.
4. Angle the probe until the splenorenal recess is seen. In a normal view, the spleen and left kidney are closely aligned, separated by a bright echogenic surface.
5. After evaluating the splenorenal recess, look above the spleen at the spleen-diaphragm interface, the look just above the diaphragm to evaluate for pleural effusion or hemothorax.
6. If it is difficult to obtain the image, slide the probe more posterior, such that the sonographer's knuckles are touching the bed. Then angle the probe such that the probe head is pointing anteriorly, with the probe at approximately 20°–30° angle to the bed (Fig. 43.23).

Normal Anatomy

When interpreting the ultrasound image, a negative exam has no free fluid. The provider will be able to successfully identify the spleen, left kidney, splenorenal recess, and subphrenic space [1] (Fig. 43.24).

Abnormal Findings

When interpreting the ultrasound image, a positive exam has free fluid. Fluid will collect in the

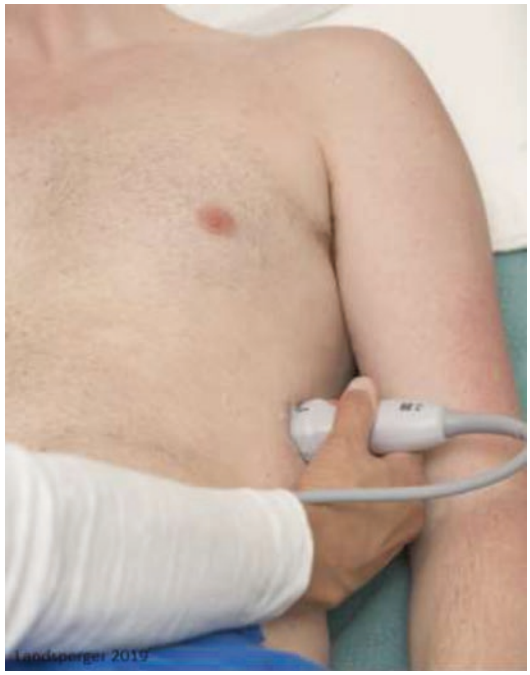

Fig. 43.23 LUQ image acquisition

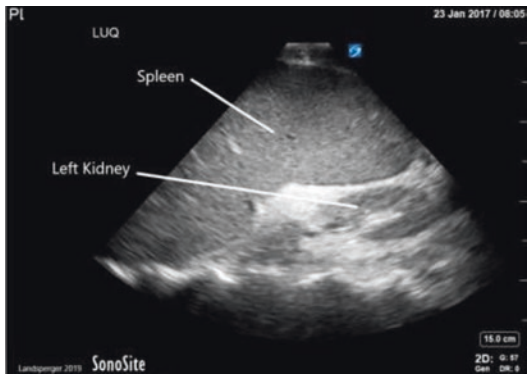

Fig. 43.24 Normal LUQ view, no free fluid present

splenorenal recess and/or above the spleen (between spleen and diaphragm). If free fluid is present in the abdomen, it will appear as a black, anechoic line between the spleen and left kidney. A pleural effusion or hemothorax will appear as a black, anechoic line or triangle just above the diaphragm [6] (Fig. 43.25).

Case-Based Learning: Free Fluid in Splenorenal Recess

A 22-year-old male presents to the emergency department with complaints of left shoulder pain, left knee pain, and abdominal pain. Patient reports he was in an ATV accident approximately 24 hours ago. This morning he awoke with severe abdominal pain, worse on the left side. On arrival to the emergency department, he is afebrile with HR 90, BP 126/72. Exam notable for diffuse abdominal tenderness. Labs notable for hemoglobin 8.5, hematocrit 25. eFAST was performed and was grossly positive showing free fluid in the splenorenal recess as well as the pelvis. CTA was performed which showed a large area of hemorrhage and active bleeding from splenic artery. Interventional radiology was consulted and patient urgently underwent coil embolization of splenic artery (Fig. 43.26).

Pelvis

The pelvic view allows the clinician to view the bladder, rectovesicular pouch (males), and rectouterine pouch (females). Additionally, when evaluating male patients, the clinician is able to view the prostate, and when evaluating female patients, the clinician is able to view the uterus.

Technique [1]

1. Use the phased array probe and point the indicator cephalad (longitudinal) or toward patient's right (transverse).
2. The patient should be lying supine.
3. Place the probe just above the pubic symphysis and look for the bladder in men and both the bladder and uterus in women.
4. Once the bladder is in view, adjust the angle of the probe to ensure the entire length of bladder is in view. Fan left to right to visualize the entire width of the bladder.
5. Once you've completed the longitudinal view, turn your probe 90° for the transverse view. Both views should be evaluated to avoid false positives (Fig. 43.27).

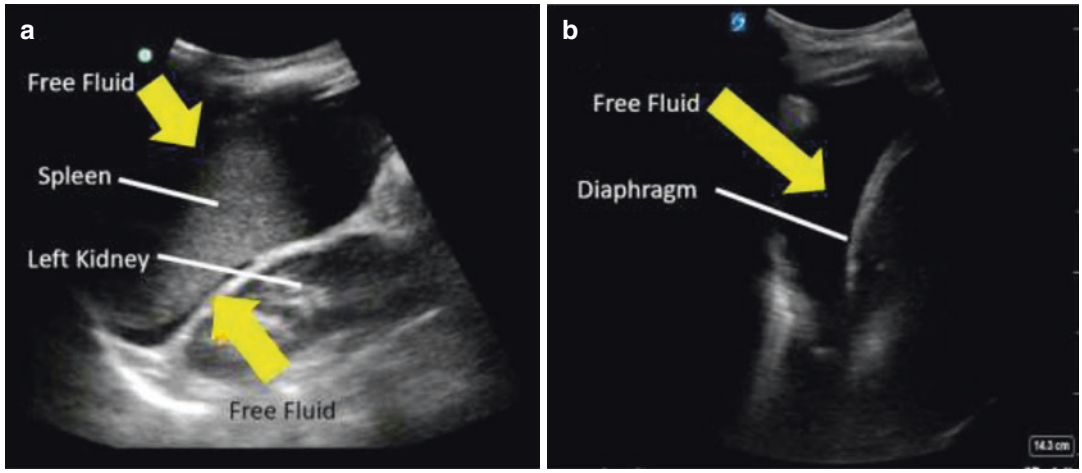

Fig. 43.25 (**a**) Abnormal LUQ view, free fluid in splenorenal recess. (**b**) Abnormal LUQ view, free fluid in pleural space

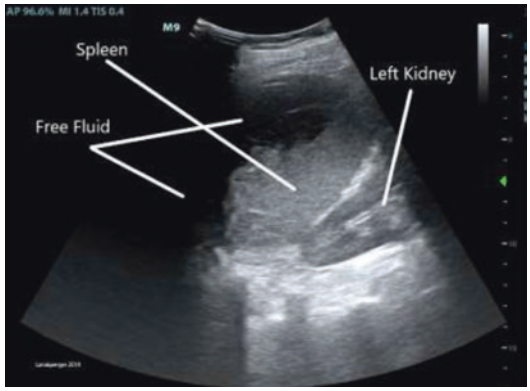

Fig. 43.26 Free fluid present in LUQ secondary to splenic artery laceration

Normal Anatomy

When interpreting the ultrasound image, a negative exam has no free fluid. The provider will be able to successfully identify the bladder, rectovesicular pouch or rectouterine pouch, and prostate or uterus [1] (Fig. 43.28).

Abnormal Findings

When interpreting the ultrasound image, a positive exam has free fluid. This is the first place fluid will collect in the lower abdomen. Fluid will collect in the rectovesicular pouch or rectouterine pouch. A significant amount of fluid will appear as a black, anechoic space between the rectovesicular and rectouterine pouch [6] (Fig. 43.29).

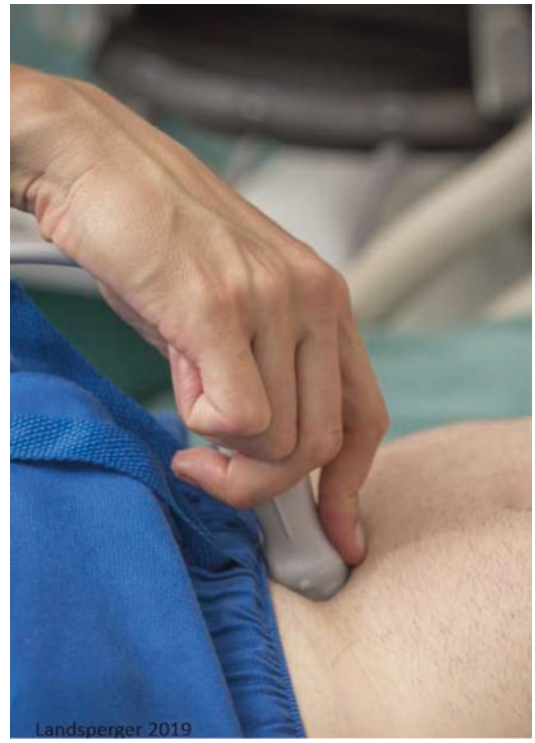

Fig. 43.27 Pelvis image acquisition

Case-Based Learning: Free Fluid in Pelvis

A pregnant 27-year-old female presents to the emergency department with complaints of vaginal bleeding intermittently for 2 weeks. On arrival to the emergency department, she is afe-

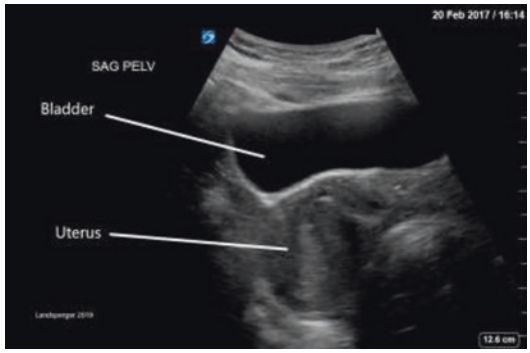

Fig. 43.28 Normal pelvic view of female patient, no free fluid present

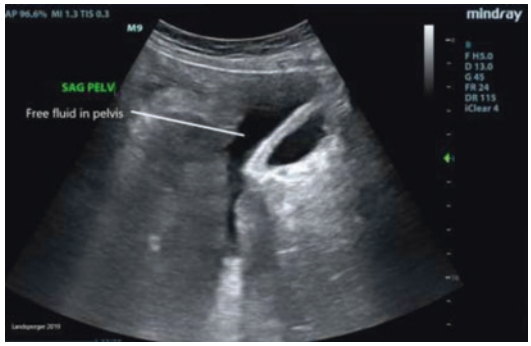

Fig. 43.29 Abnormal pelvic view, free fluid present

brile, with HR 102, BP 100/64. Patient reports last menstrual period about 8 weeks ago. Exam notable for lower abdominal tenderness. Labs notable for beta Hcg 5966 otherwise unremarkable. eFAST performed and revealed trach free fluid in the pelvis. OB was consulted and performed a transvaginal ultrasound which showed ruptured left ectopic pregnancy. Patient was urgently taken to the operating room for an exploratory laparotomy (Fig. 43.30).

Scanning Tips and Tricks: Abdominal

Ultrasound image acquisition can be difficult. It is important to optimize the patient's positioning as well as the providers. At times, placing the patient in Trendelenburg helps optimize the image. Dimming the lights will allow for better contrast on monitor and assist gain adjustment. Make sure to fan through the entire anteroposterior dimension of organs in order to obtain adequate evaluation for free fluid. In the RUQ/LUQ views, be sure

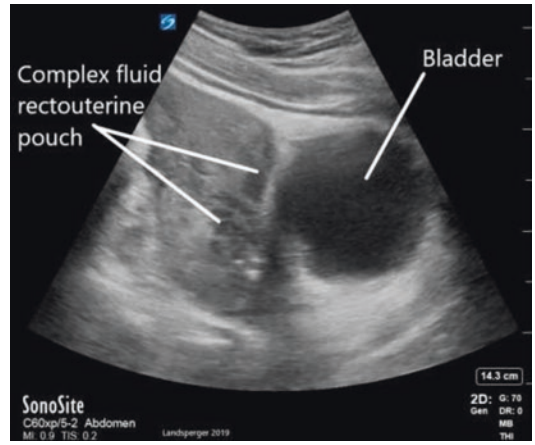

Fig. 43.30 Abnormal pelvic ultrasound, ruptured ectopic pregnancy

to have the kidneys in field of view. This ensures you are imaging posteriorly enough to pick up free fluid. When evaluating the pelvis, the best opportunity to acquire a good sonographic view is before the placement of a Foley catheter. Never forget the basics of ultrasonography such as the use of sufficient amount of gel to facilitate good ultrasound wave transmission and the proper inclination of the probe to avoid interference from any bone structures.

Thoracic Views

Pleural Space

Going back to the aim of performing an eFAST exam, we want to identify if there is lung collapse or free pleural fluid. Begin with choosing a lung field, either left or right. Obtaining images anteriorly along the upper portion of thorax will yield data that can help with the diagnosis of pneumothorax. Obtaining images at the base of the lung field will allow for diagnosis of a pleural effusion.

Technique [1, 9]

1. Use the phased array probe and position the indicator cranially.
2. The patient should be lying supine.
3. Place the probe along the mid-clavicular line anywhere below the clavicle and above the nipple.

4. Position the probe so that the waves can pass between a rib space, and a brightly echogenic surface will appear. This is the visceral parietal pleural interface (VPPI). It will appear as moving or shimmering, representing aerated sliding lung in the case of a normal study.
5. After evaluating both anterior pleural fields, proceed to imaging of each pleural base. The indicator on the phased array probe remains orientated cranially. Position the probe along the mid-/posterior axillary line.
6. In the case of imaging the right pleural base, identify the liver and move the position of the probe cranially. The diaphragm can be identified as a bright echogenic surface, curving along with the liver. In the case of a pleural effusion, free fluid can be identified as an anechoic fluid collection appearing mostly black.
7. In the case of the left pleural base, identify the spleen and slowly move the probe cranially. Again, note the diaphragm and proceed to evaluate for free pleural fluid (Fig. 43.31)

Normal Anatomy

When interpreting the obtained image, a negative exam will have no collapsed lung or free pleural fluid. The provider will be able to successfully identify the VPPI between two ribs with sliding lung and the diaphragm at the base of the pleural field without any surrounding pleural fluid. The provider may also visualize A-lines and B-lines.

A-lines are horizontal reverberation artifacts generated by the ultrasound machine. They can be seen at regular intervals. Unfortunately, they can be found in both a pneumothorax and normal lung [1, 9].

B-lines are vertical lines emanating from the VPPI, generated by the alveoli. They will appear to have a comet tail radiating to the lower portion of the screen. They are always dynamic in that they move synchronously with sliding lung. The presence of B-lines does effectively rule out the possibility of a pneumothorax [1, 9] (Figs. 43.32 and 43.33).

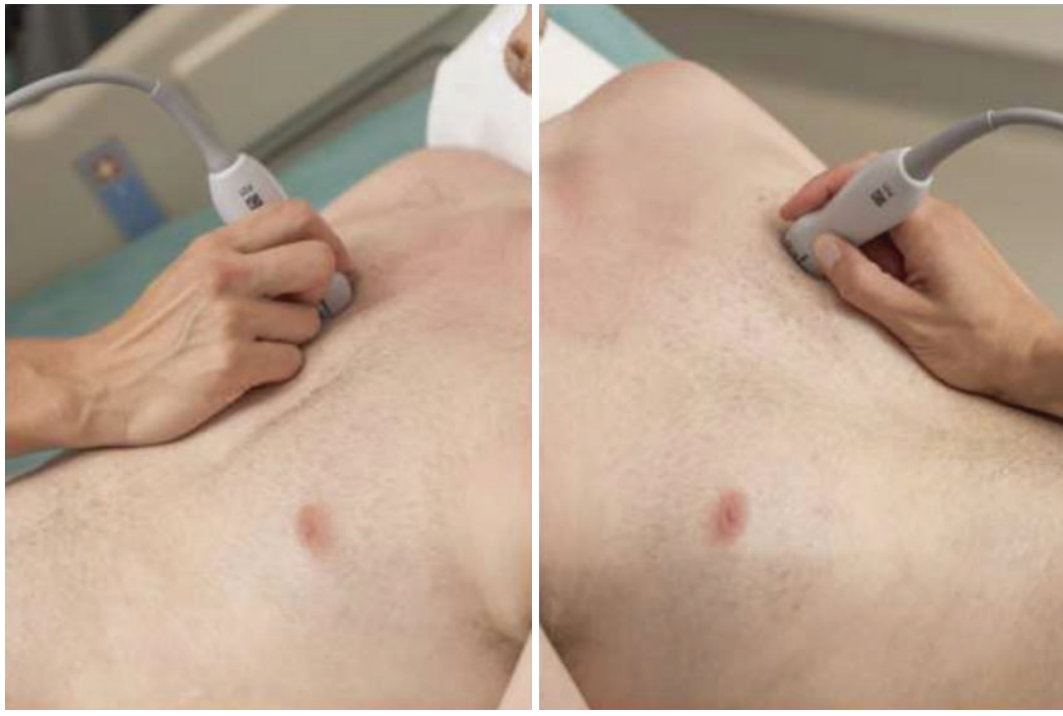

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Fig. 43.31 Right and left thoracic image acquisition

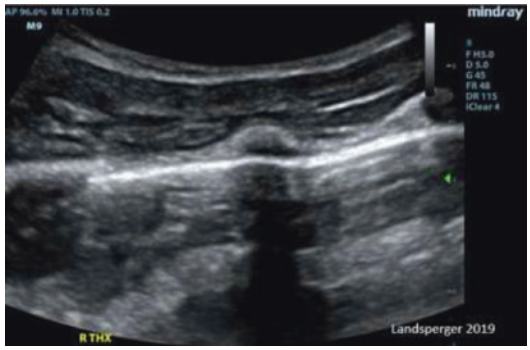

Fig. 43.32 Normal view right anterior thoracic

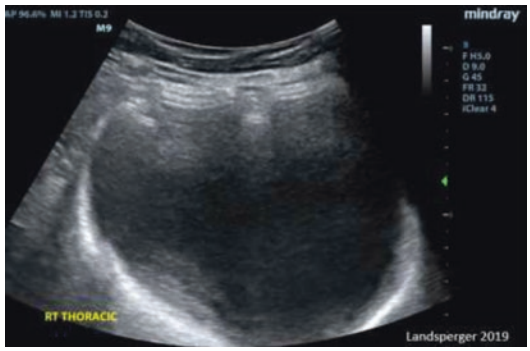

Fig. 43.33 Normal view right basilar thoracic

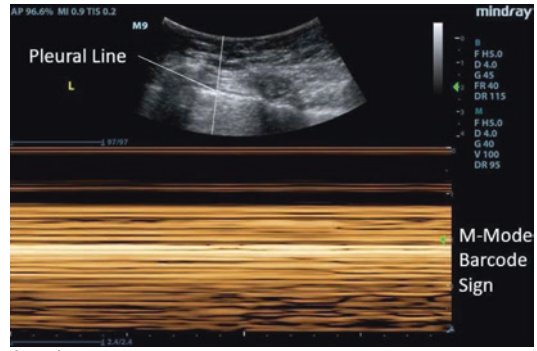

Fig. 43.34 Abnormal anterior thoracic image, pneumothorax present

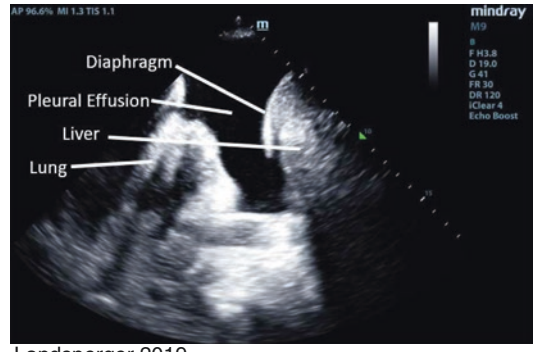

Fig. 43.35 Abnormal basilar thoracic image, pleural effusion present

Abnormal Findings

When interpreting an abnormal ultrasound image, a positive exam demonstrates lack of sliding lung and/or free pleural fluid. A small pneumothorax can be easily missed. Scanning in the parasternal region on either side of the sternum can help with the diagnosis [1, 9]. If collapsed lung is present, the VPPI will appear to be static rather than be moving dynamically. In cases with subcutaneous emphysema, E-lines can be visualized at the level of the chest wall. The presence of subcutaneous emphysema will often obscure visualization of the pleura. If free pleural fluid is present in the basilar region, it will appear as an anechoic black collection just above the diaphragm (Figs. 43.34 and 43.35).

Case-Based Learning: Pleural Effusion

A 30-year-old healthy female presents to the emergency department after being involved in a motor vehicle accident. She was a restrained driver with significant intrusion of another vehicle on the driver side and also had loss of consciousness. The patient was complaining of left-sided abdominal and chest pain. The vital signs were as follows: HR 110, BP 100/50, SpO_2 95% on non-rebreather, GCS 14. After primary survey, the patient was taken to CT scan. After performing the head CT, the patient became hypotensive and began to show signs of shock. The decision was made to complete the remaining portions of the CT scan, demonstrating a large pleural effusion, in this clinical setting likely a hemothorax. A chest tube was inserted; the patient was transfused and stabilized. In this case, performing an eFAST exam would have helped diagnose the hemothorax earlier and prevented the risky situation of having an unstable patient in radiology (Fig. 43.36).

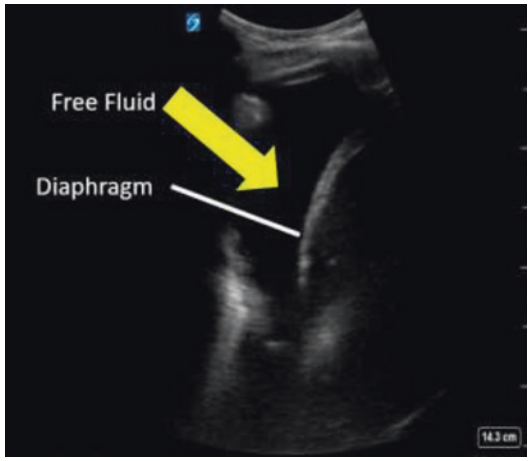

Fig. 43.36 Abnormal thoracic ultrasound, hemothorax

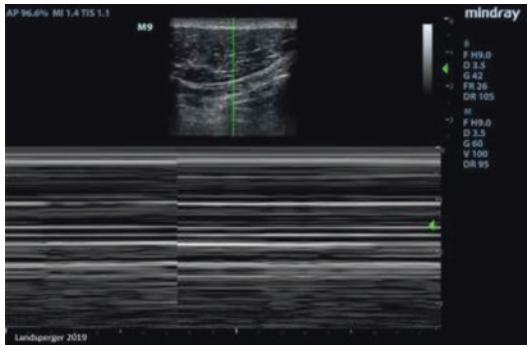

Fig. 43.37 Abnormal thoracic image, pneumothorax

Case-Based Learning: Pneumothorax

A 72-year-old man admitted to the intensive care unit with sepsis from pneumonia. During the course of his admission, he needed mechanical ventilation and ultimately needed vasopressors for hypotension. A central venous catheter was placed into the right subclavian vein. The provider finished the procedure, and while cleaning up the patient developed hypoxia. A portable chest X-ray had already been ordered, but there was a delay in the arrival of the radiology technician. Bedside ultrasound was utilized to quickly diagnose a post-procedure right-sided pneumothorax. A pigtail catheter was used to decompress the pleural space (Fig. 43.37).

Scanning Tips and Tricks: Thoracic

If there is any doubt of the presence of sliding lung, utilize M-Mode on the ultrasound. Using M-Mode, position the vertical line in between two ribs, projecting the vertical line into the pleural space. If sliding lung is present, the "seashore sign" can be visualized. If sliding lung is absent, the images obtained via M-Mode will appear to be a barcode or straight horizontal lines across the ultrasound screen.

At times, obtaining adequate images can be difficult. Ensuring appropriate environmental lighting and gain will always assist with image acquisition. If difficulty is encountered penetrating the rib spaces, widening of the spaces can be done by having the patient raise their arms above their head. Difficulty can also be encountered when imaging the basilar region(s) with regard to dynamic movement of the lungs and the images being obscured by the ribs. If the patient is able, asking them to take a deep breath and holding it should allow for better ultrasound windows.

Subxiphoid Cardiac View

When evaluating the pericardium in the setting of trauma, there is only one objective, and that is to identify if there is a pericardial effusion. This can be easily and quickly obtained by imaging the heart and pericardium by imaging via a subxiphoid approach.

Technique [8]

1. Use the phased array probe and point the indicator to the patient's right flank.
2. The patient should be lying supine.
3. Place the probe just below the inferior projection of the xiphoid process. Angle the probe so that it is nearly parallel to the patient and pointing toward the left shoulder. In a normal view, both the heart and left lobe of the liver should be visualized.
4. Evaluate the pericardial space for any evidence of anechoic black fluid (Fig. 43.38).

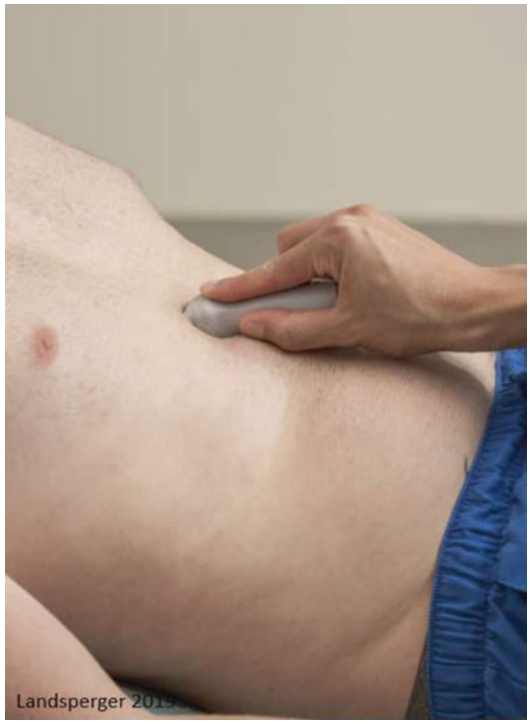

Fig. 43.38 Subxiphoid view image acquisition

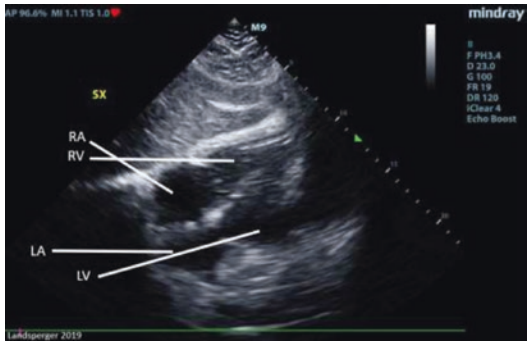

Fig. 43.39 Normal view subxiphoid

Normal Anatomy

When interpreting the ultrasound image, a normal or negative exam should have no pericardial effusion. The provider should be able to identify the left lateral edge of the liver, the right atrium, left atrium, right ventricle, and left ventricle (Fig. 43.39).

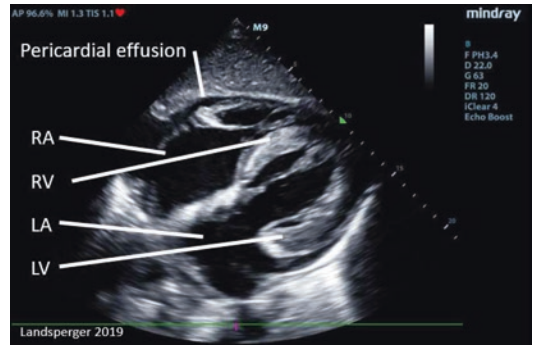

Fig. 43.40 Abnormal subxiphoid image, pericardial effusion present

Abnormal Findings

When interpreting obtained images of the heart via a subxiphoid approach, a positive exam has free fluid. Again, free fluid will appear to be anechoic and black. The pericardium is more hyperechoic than the surrounding heart muscle. An effusion can be seen adjacent to the right atrium or ventricle, but if seen circumferentially, there should be concern for a pericardial effusion [8] (Fig. 43.40).

Case-Based Learning: Pericardial Effusion

A 79-year-old female presented to the emergency department with a 2-day history of lethargy and malaise. During the history-taking portion of her exam, it was noted that she had a recent CABG and was discharged from the hospital only 1 week ago. Her vital signs were significant for hypotension and jugular venous distention. By performing a simple bedside evaluation of the heart with an ultrasound, it was discovered that the patient had a pericardial effusion. When compared to the echo prior to discharge, it was a new effusion. The cardiac surgery team was able to take the patient to the operating room for a pericardial window and drain the effusion (Fig. 43.41).

Scanning Tips and Tricks: Subxiphoid View

When performing an evaluation of the pericardium via a subxiphoid approach, the provider

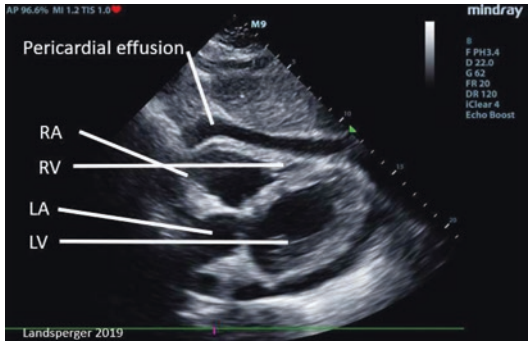

Fig. 43.41 Abnormal subxiphoid view, pericardial effusion

must hold the probe from the top and apply pressure to force the transducer into the patient's abdomen.

In some normal healthy patients, a small amount of pericardial fluid can be seen in the dependent areas of the heart. This must be correlated to the clinical situation [8].

In the case of a large hemothorax, pericardial fluid may be obscured. In these instances, it is advisable to repeat the evaluation of the pericardium after the hemothorax has been drained [8].

Acknowledgments Photo credits: Special thank you to Will Noblit, photographer, and Will Rasmussen, ultrasound model.

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Bedside Cardiac Ultrasound in the Intensive Care Unit

44

Casey Scully and Rita Brintzenhoff

Introduction

Ultrasound is widely used among critical care providers for both diagnostic evaluations and procedural guidance. The proliferation of this as a tool is guided by the convenience, portability, and safety it provides. Focusing on decreasing mortality and the obvious benefit of early recognition of shock, as described by Rivers in 2001 [1], critical care ultrasound has broad utility for diagnostic capabilities in not only shock, but trauma, cardiac failure, hemorrhage, and resuscitation efforts for the critically ill patient. As such, ultrasound has become a fundamental instrument in the armamentarium of critical care medicine.

Improvements in ultrasound training are contributing to broader understanding of ultrasound applications among physicians and advanced practice providers (APP). This training has become increasingly standardized in critical care fellowships [2] and is utilized in disciplines where rapid assessment of the critically ill is vital. Ultrasound additionally has exciting new indications and applications for use in many organ systems.

A structured approach to critical care evaluation promotes efficient and rapid care, which is demanded in emergent scenarios. The convenience, speed, and effectiveness of ultrasound provide substantial and essential benefit in critical care, where time and efficacy are essential to patient outcomes. Ultrasound machines have evolved to be portable and accessible, with recent innovative models that fit into a white coat pocket. The ultrasound's portability allows for evaluation at bedside, giving providers real-time insight to drive care. Bedside ultrasound may be provided with convenience and speed, requires no coordination or scheduling with radiology, and has no ionizing radiation exposure [3]. Ionizing radiation exposure is a focus of providers in all specialties of medicine in which providers apply judicious and appropriate imaging [2]. Bedside ultrasound helps diagnose and aids the interventional assistant with procedures such as central line placement, thoracentesis, arterial line placement, and other applications discussed in other chapters.

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Bedside Echocardiogram Indications

A primary focus in critical care is maintaining adequate tissue perfusion. Specifically, cardiac function, whether the primary cause of the condition or sequela from overall systemic ailment, is necessary for critical care providers' interventions and medications to maintain adequate perfusion. Bedside echocardiogram can evaluate for multiple conditions, allowing for a rapid assessment and development of a differential diagnosis. The main purpose of the exam is to evaluate for cardiac function including estimates of the ejection fraction, volume status, presence of pericardial effusion, and possible signs that indicate diagnoses, for example, McConnell's sign.

Contraindications/Limitations

Bedside echocardiogram has limitations to the evaluation of a patient. The provider must always consider the time needed to perform and complete the exam and the current condition of the patient. A decision based on the information obtained from the exam could change the clinical course and aid in patient care to abate the present type of shock. Limitations also include the ability of the user to perform and interpret the exam, the quality of the images provided, and barriers to ultrasound image acquisition. A patient's body habitus may limit images, for example, minimal intercostal space or large amounts of adipose tissue. Additionally, presence of subcutaneous emphysema can prohibit ultrasound image acquisition as well.

Considerations for infection prevention are paramount. Providers must always consider the safety of the area to be scanned. Overlying infection and open wounds that ultrasound gel could inoculate in other areas and the inability to obtain proper images in order to avoid infected areas are contraindications [4, 5].

Risks/Benefits

Bedside echocardiogram is a valuable tool in the provider's bedside armament. Critical cardiac information can be obtained quickly with little added risk to the patient, which can be effectively mitigated. Few diagnostic procedures can be executed as quickly that provide sufficient cardiac insight to impact diagnoses. As mentioned above, ultrasound portability, availability, and lack of reliance on other departments or groups allow for near-immediate application, providing a major advantage for critical care.

The two prevalent risks are effective time management and infection proliferation. A strong understanding of bedside echocardiogram results from experience over a long period will aid the provider in determining if and when a bedside echocardiogram should be used. Great attention should be given to infection control during each use, with careful and judicious application of gel, as well as consideration of multiple ultrasound locations on the body. Collectively, these risks are mitigated to very low levels by experienced providers. As ultrasounds use sound waves to interrogate the body, no ionizing radiation exposure is applied.

Preparation

To use the ultrasound machine properly, the user must understand the basics of how an ultrasound functions to get the most out of each use. As mentioned in the EFAST exam chapter, the physics of ultrasound help describe the basics. As brief review, sound waves are transmitted from the ultrasound machine in short pulses to the patient using the probe. The sound waves then travel through the body and hit structures that send signals back to the probe. Depending on the density of the structures, sound waves can travel further until they too are reflected to the machine. Via the piezoelectric system, the crystals in the probe head detect the returned information and create

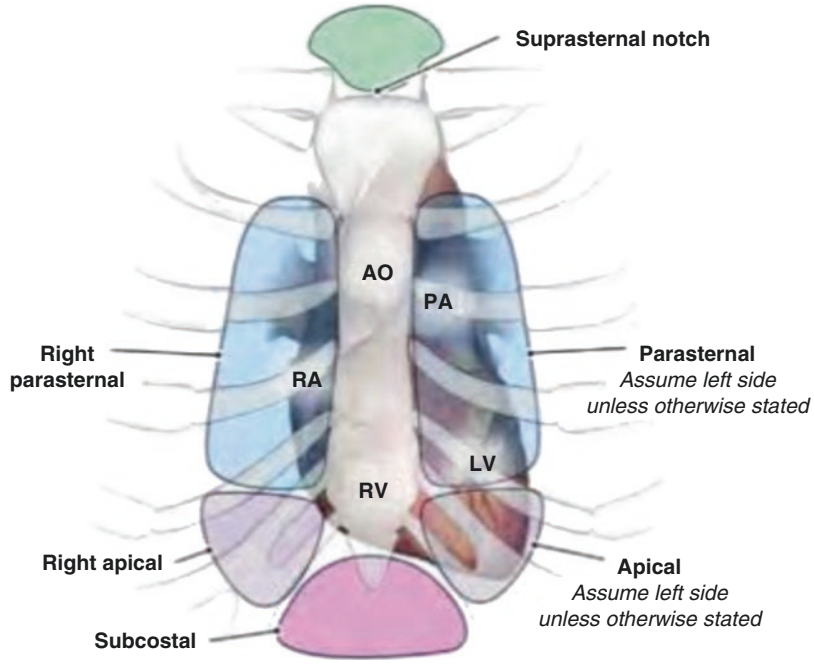

Fig. 44.1 General external landmarks for cardiac views. (Reprinted from Mitchell et al. [11]. With permission from Elsevier)

an image based on the speed of the return [6]. Also, the intensity of the sound wave returns different images on the screen defining the internal densities of the body [6].

For an ultrasound evaluation, the provider needs a couplant, a machine, and a general idea of depth and anatomic location they are investigating. Recall orientation planes; these are further depicted in Figs. 44.1 and 44.2. This will aid in understanding the cardiac anatomy and images typically obtained to evaluate cardiac structures. The position of the heart is oblique in the chest, generally directed toward the left hip. The views described below are used most frequently in echocardiography. Images are obtained when the ultrasound beam cuts a 2D line through the anatomic axis of the heart [7].

Ultrasound gel (couplant) serves as a medium that allows ultrasonic waves to pass from the end of the probe to the patient and is paramount in obtaining adequate images. Generous application aids in window acquisition, although, as mentioned above, remain mindful of potential infection proliferation. Bedside echocardiogram can be performed in the supine position or the left lateral decubitus position to bring the heart closer to the chest wall as recommended by the American Society of Echocardiography.

Procedure

The bedside echocardiogram consists of four main views: parasternal long axis, parasternal short axis, apical four-chamber, and subxiphoid. Refer to Fig. 44.3 to view the probe positioning. Each position obtains a slightly different evaluation of the heart and is described below with image depiction. Figure 44.3 illustrates the parasternal positions labeled below as A, apical labeled as C, and subxiphoid as B.

The probe selection to obtain these exams should be a low-frequency phased array probe. Each view will provide information that will help diagnose the primary etiology and guide for further intervention. The key to a good cardiac exam

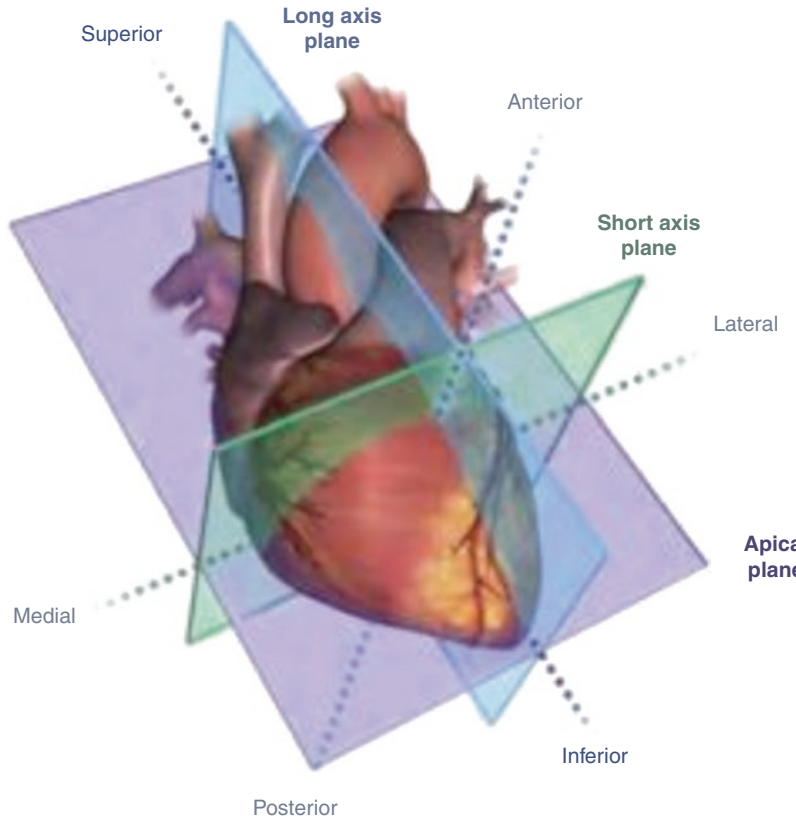

Fig. 44.2 Cardiac planes. (Reprinted from Mitchell et al. [11]. With permission from Elsevier)

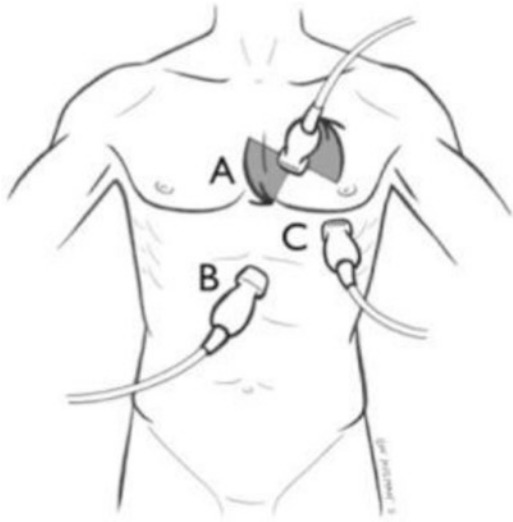

Fig. 44.3 Probe positioning for main cardiac views on chest. (Reprinted from Seif et al. [9]. With permission from Creative Commons License 3.0: https://creativecommons.org/licenses/by/3.0/)

is an adequate window; however cardiac windows are limited by the structure of the chest wall and intercostal spaces. This is the major challenge to providers in obtaining the aforementioned images. Small circular motions, rocking, and fanning of the probe are very useful in optimizing images obtained and highly recommended to obtain the desired diagnostic evaluation images.

There are two important rules to remember: First, the top of the viewing screen is where the transducer is touching the patient, and the bottom depicts deeper structures. Second, the orientation marker on the transducer and the orientation marker on the viewing screen *always* point in the same direction. Ultrasonic images of bedside echocardiograms are unique in that images are reversed. The indicator on the machine will appear on the opposite side of the screen [8].

Parasternal Long Axis

Start with the probe in the third intercostal space just to the left of the sternal border, and make small circles advancing to the fourth intercostal space. The probe indicator should be directed toward the patient's right shoulder (Fig. 44.4). The expected depth to use is approximately 16 cm, but this is different for each patient. An image will appear and small motion to optimize the image is recommended. Inspiration and expiration will possibly alter the position of the heart. Remember that the image orientation on the screen is reversed from the orientation of the ultrasound probe; in order to focus more on the apex seen on screen left, you need to direct the ultrasound probe toward the right. It is helpful to always keep in mind the orientation of the heart in the chest to direct your movements. Parasternal long axis is the best single view for evaluating overall cardiac function and estimating ejection fraction [9, 10]. Remember the anatomic definitions to recognize the cardiac structures visualized along the long axis of the heart. This view captures the left atrium, mitral valve, left ventricle, apex, interventricular septum, left ventricle outflow tract, aortic valve, aorta, right ventricle, and possibly the right pulmonary artery (see Fig. 44.5) [11].

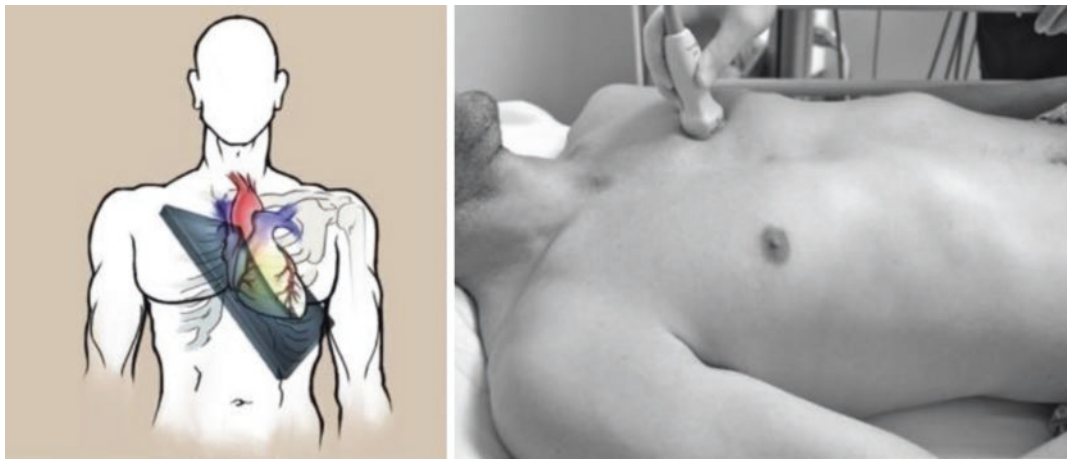

Fig. 44.4 Parasternal long axis. (Images and figures courtesy of Dr. Teresa Wu and Dr. Nicolas Hatch from www.SonoSupport.com, [13])

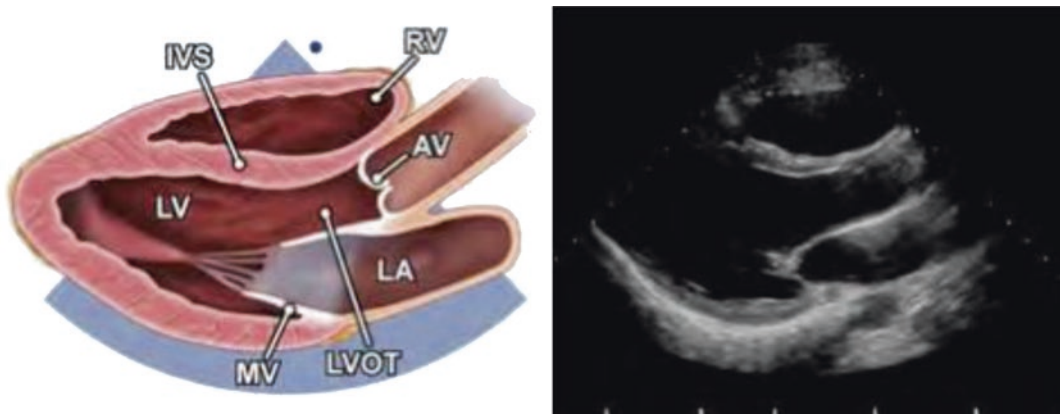

Fig. 44.5 Parasternal long axis. (Reprinted from Mitchell et al. [11]. With permission from Elsevier)

A pericardial effusion can be visualized in any view, but the parasternal long will identify the effect on filling best. This view is best seen with the patient in the supine position. Rolling patients to the left lateral decubitus position and placing their left arm behind their head will often provide better apical and parasternal views.

Parasternal Short Axis

Beginning with the location of the parasternal long axis view, turn the probe indicator to the patient's left shoulder to view the parasternal short. This is a 90-degree clockwise rotation, which gives a cross section of the heart as seen in Fig. 44.6. This can evaluate cardiac activity at multiple levels by directing the probe head up and down, thereby changing the angle of inclination between the probe and patient, or "fanning" the probe from the base of the heart to the apex of the heart visualizing the aortic valve, mitral valve with papillary muscles, and then the apex. This shows a quick evaluation of the contraction, or "squeeze," of the heart. A contraction can be observed with the shrinking of the rounded left ventricle into a smaller circular image. A thick wall of muscle of the left ventricle and, conversely, a thinner lateral wall of the right ventricle can be appreciated in this view (Fig. 44.7) of

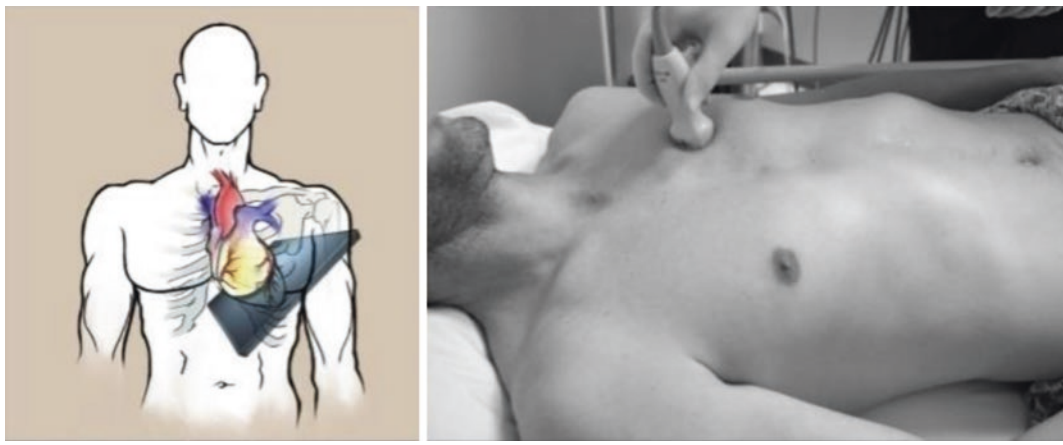

Fig. 44.6 Parasternal short axis. (Images and figures courtesy of Dr. Teresa Wu and Dr. Nicolas Hatch from www.SonoSupport.com, [13])

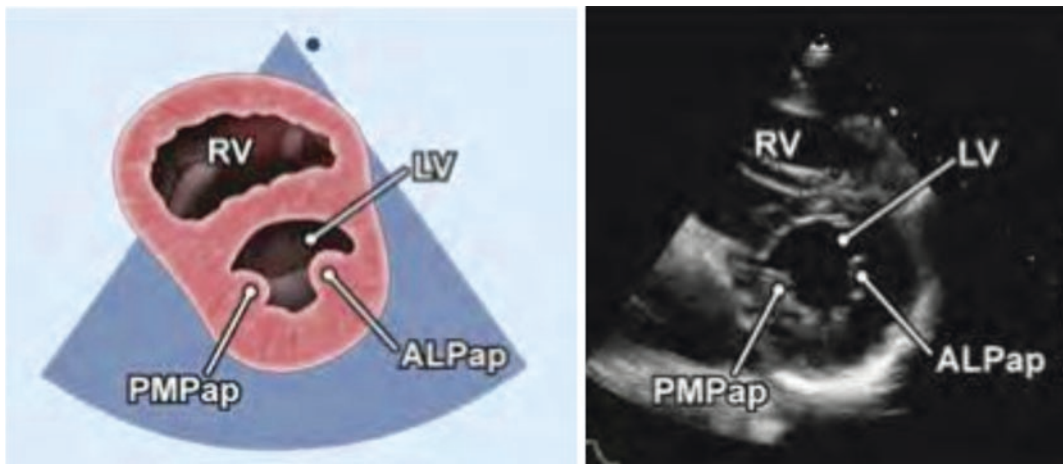

Fig. 44.7 Parasternal short axis. (Reprinted from Mitchell et al. [11]. With permission from Elsevier)

anterior papillary muscles in parasternal short. Patients with truncal obesity will have better parasternal views, while subcostal views will be difficult [12].

Apical Four-Chamber View

The apical position is best found at the point of maximal amplitude on the left side of the chest near the midaxillary line, near the fifth intercostal space seen in Fig. 44.8 [11]. The indicator marker should be directed toward 3:00 [12, 13]. This view allows the user to visualize structures of the heart including both atria, ventricles, and the septal dividers. Keep in mind the LV will be oriented on the right and RV, usually considerably smaller, is oriented on screen left (Fig. 44.9). If unable to obtain images, try moving up or down an intercostal space and fanning the probe within each space. This view provides the best window to evaluate for valve dysfunction. The tricuspid valve (right side of image) and mitral valve (left side of image) are visualized and parallel in the

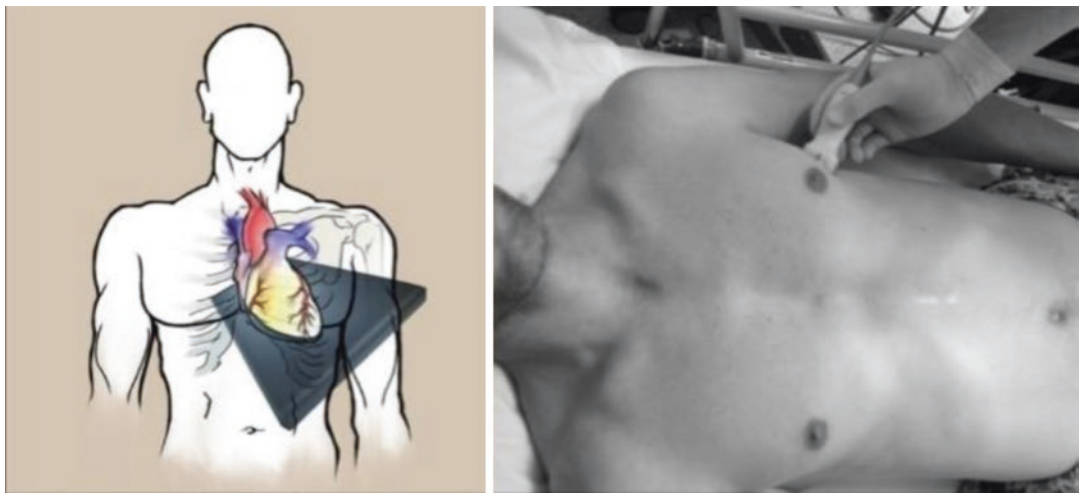

Fig. 44.8 Apical four-chamber view. (Images and figures courtesy of Dr. Teresa Wu and Dr. Nicolas Hatch from www.SonoSupport.com, [13])

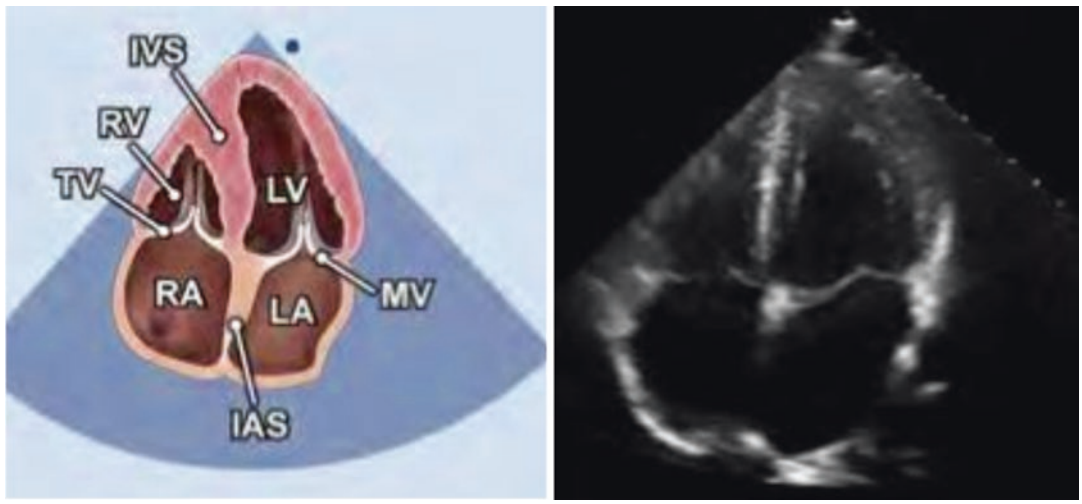

Fig. 44.9 Apical four-chamber view. (Reprinted from Mitchell et al. [11]. With permission from Elsevier)

image [11, 12]. Additional structures easily visualized with this view include the right atrium, tricuspid valve, right ventricle, left atrium, mitral valve, left ventricle, interventricular septum, and apex. This view will provide excellent comparison of right and left ventricular size and function.

Subcostal View

The subcostal view positions the probe just below the xiphoid process, slightly to the patient's right. Transducer is oriented toward the patient's left shoulder – between suprasternal notch and left clavicle, with the transducer marker oriented to 3:00 (Fig. 44.10). This view is often used with the patient evaluations during trauma eFAST. It uses the liver as an acoustic window to view the deeper lying heart. Limitations on this view include body habitus, abdominal or gastric air, as well as post-surgical dressings or negative pressure vacuum-assisted closure devices. This is an effective view to evaluate cardiac activity in PEA arrest, as well as comparing size and function of right and left ventricles. Patients with COPD will have great subcostal views but poor parasternal. Main cardiac structures visualized in the subcostal view include the right atrium, tricuspid valve, right ventricle, interventricular septum, left atrium, mitral valve, and left ventricle (Fig. 44.11).

Pathology

Circulatory failure is common in the ICU. Utilization of a structured approach to the hypotensive patient using the above views is critical to direct care. Items to focus on are the assessment of LV function including chamber size and contractility, volume status, valve evaluation, and effusion evaluation [10]. To evaluate LV function, first use the parasternal long view. A rapid, subjective assessment of change in chamber size with systole can indicate LV function. Decrease in chamber size of approximately 30% on LV contraction generally indicates preserved LV function. Additionally, symmetric wall contraction can be observed by placing your finger in the center of the LV cavity on the US screen and visualizing all locations of the LV wall contract symmetrically toward your finger. An additional mechanism to determine LV function is the observation of the mitral valve and mitral annulus excursion. In a normal contractile state, the anterior mitral leaflet will be seen touching or close to the septal endocardium during early diastole as seen in Fig. 44.12 [9]. There is a correlation between the mitral excursion and the left ventricular contractile status, and there is an inverse proportion of the distance between the mitral valve and the LV contraction. This can also be seen on apical four-chamber view. Refer below to a magnified view of the ventricle and mitral valve.

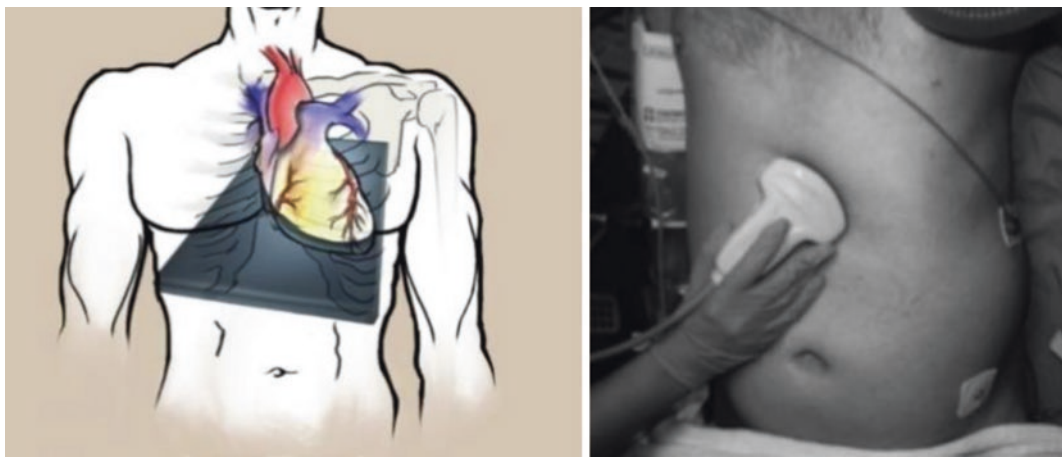

Fig. 44.10 Subcostal view. (Images and figures courtesy of Dr. Teresa Wu and Dr. Nicolas Hatch from www.SonoSupport.com, [13])

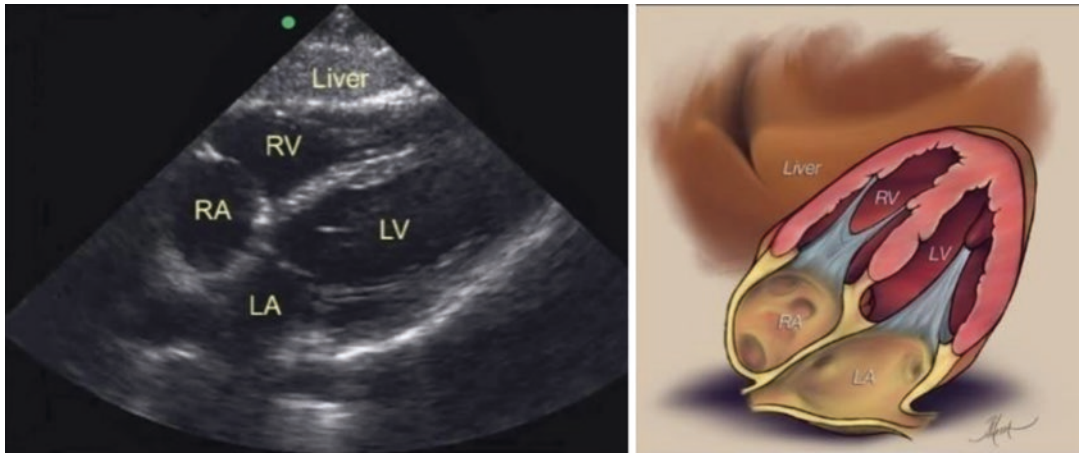

Fig. 44.11 Subcostal view. (Images and figures courtesy of Dr. Teresa Wu and Dr. Nicolas Hatch from www.SonoSupport.com, [13])

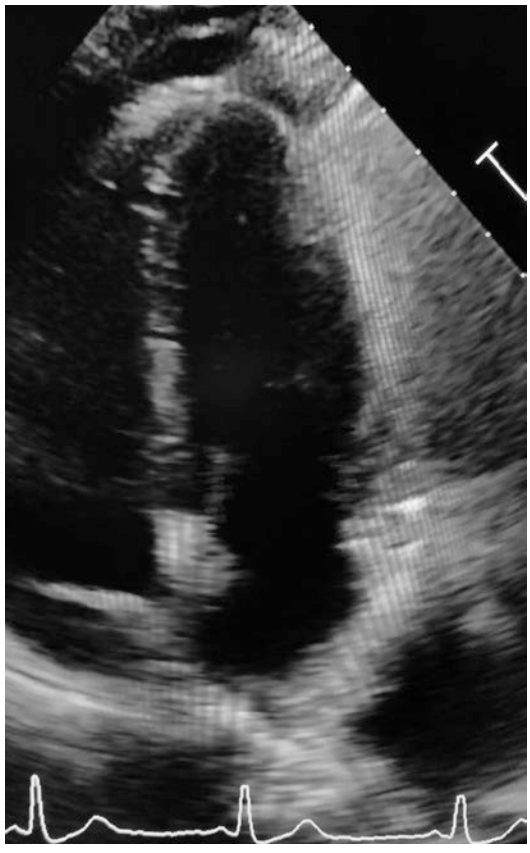

Fig. 44.12 Mitral valve leaflet touching or close to septum at early diastole

Figure 44.12 depicts an open mitral valve that nears the septum indicating a sufficient ejection fraction. This can be evaluated formally by E-point septal separation; >1 cm of separation between the septal endocardium and the mitral valve indicates low ejection fraction [9]. Evaluation of the mitral annulus excursion during systole (mitral annular plane systolic excursion (MAPSE)) can also indicate LV function. In the PSL view, identify the annulus of the mitral valve and monitor its movement toward the apex during systolic contraction. An excursion distance of 1 cm correlates with adequate LV function. When LV function is found to be depressed, consider pressors with inotropic effects to aid in oxygen delivery. Providers must always consider the etiology of the underlying shock and treat accordingly.

Additionally, in hypovolemia quick volume status evaluation can be made in multiple views. When identified, effacement of the ventricles shows an extreme low volume status and requires resuscitation. Preload responsiveness could be ascertained with repeated imaging of the LV after administration of fluid. Additional evaluation of the IVC (not pictured) could take a step further in the diagnosis of hypovolemia observing collapsibility during inspiration.

Other physiologic findings in hypotensive patients, such as pulsus paradoxus or Beck's triad, are of lower sensitivity and are easily diagnosed using a cardiac ultrasound to differentiate tamponade [9]. Bedside clinicians should look for either atrial or ventricular collapse to confirm the diagnosis of tamponade as the causative etiol-

ogy leading to hypotension or cardiac dysfunction as seen in Figs. 44.13 and 44.14 with each view labeled [10].

Parasternal Long View

Pulmonary embolism must be considered for severe hypoxia and hemodynamic unstable patients. This is a challenging and advanced imaging diagnosis, but with understanding the fundamental bedside ultrasound cardiac views, it is possible to identify signs on views. McConnell's sign is a well-known finding with right ventricular dysfunction akinesis of the mid free wall and normal apex function seen on four-chamber view [14].

Parasternal short view of an extremely dilated RV creating a "D" sign of the LV that is normally

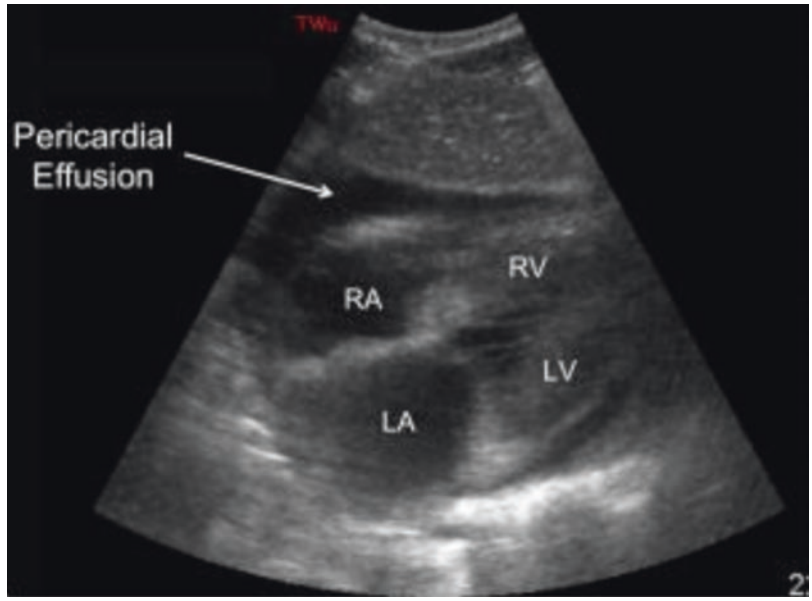

Fig. 44.13 Pericardial effusion. (Images and figures courtesy of Dr. Teresa Wu and Dr. Nicolas Hatch from www.SonoSupport.com, [13])

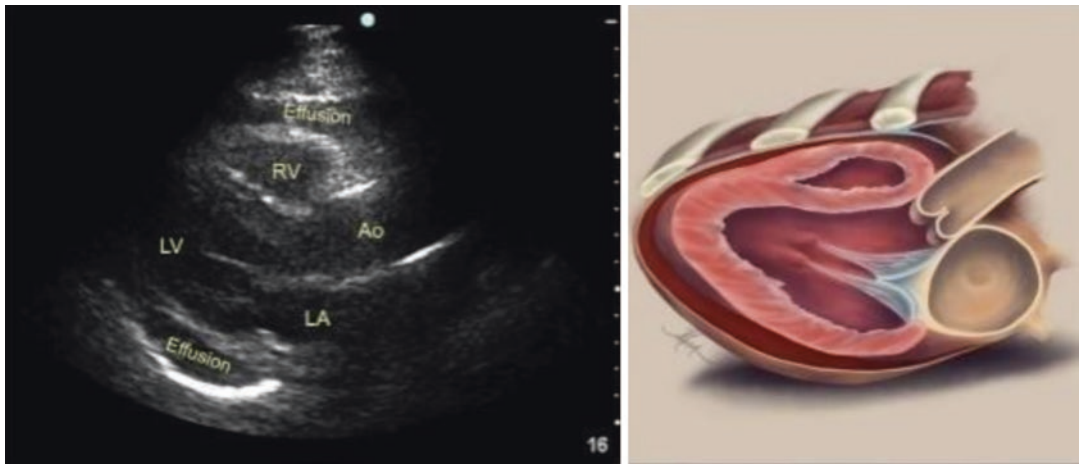

Fig. 44.14 Pericardial effusion. (Images and figures courtesy of Dr. Teresa Wu and Dr. Nicolas Hatch from www.SonoSupport.com, [13])

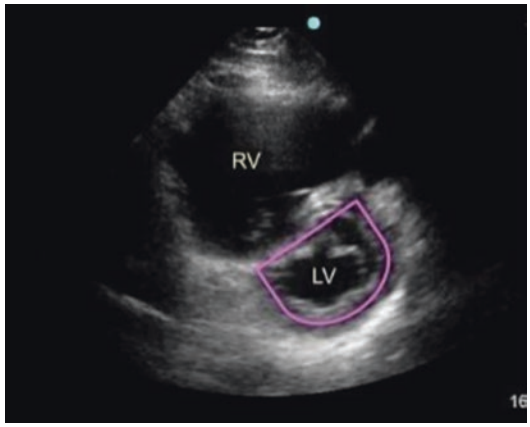

Fig. 44.15 Dilated right ventricle seen in parasternal short. (Images and figures courtesy of Dr. Teresa Wu and Dr. Nicolas Hatch from www.SonoSupport.com, [13])

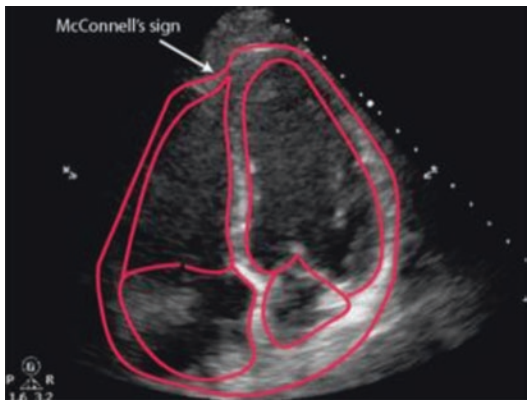

Fig. 44.16 Dilated right ventricle without outline, apical view. (Courtesy of Critical Care Sonography)

circular and could indicate a right ventricular strain as well (Figs. 44.15 and 44.16 [13–15]).

Complications

There are few complications of using the ultrasound machine at bedside. As previously stated, ultrasound uses sound waves to create images and provide diagnostic information. Additionally, a coupling gel is used to connect sound waves to the body. Care must be maintained to not cross-contaminate any bacteria to the evaluation site that could inoculate bacteria to an open wound or incision [4, 5].

Keys to Success, Perils, and Pitfalls

Even an experienced provider can get lost in an exam; remember two rules: the top of the viewing screen is where the transducer is touching the patient, and the orientation marker on the transducer and the orientation marker on the viewing screen *always* point in the same direction [8]. Small circular motions help keep windows in view around the ribs and adjust the angle of the sound wave as well as "rocking" and "fanning" the probe to obtain images. Inspiration and expiration will possibly alter the position of the heart; keep in mind the evaluation is dynamic. Lastly, scan in a systematic fashion with every patient. The evaluation will become more familiar, and the skill level of the provider will increase with each attempt. The power of the tool is only as good as its user.

Organized Evaluation

Critical care providers faced with unstable and critically ill patients are tasked with the rapid detection of causative agents. Specialty exams in the ultrasound department have been created to perform detailed diagnostic evaluations on individual organs and organ systems. For acutely ill symptomatic patients with unknown etiology needing rapid assessment, the protocolized ultrasound approach is a great diagnostic tool to help direct resuscitation, further imaging requirements, and interventions.

Some of the more popular critical care ultrasound protocols to evaluate shock include RUSH and POCUS. Further delineation in organ system evaluations includes abdominal evaluations, e.g., the ACES exam, pulmonary exams included FALLS and BLUE protocol, and FOCUS protocol evaluation is specifically cardiac [9, 16]. Below is a visual depiction of the sequence of the RUSH exam and the differentiation of shock with the interpretation of the diagnostic evaluation in

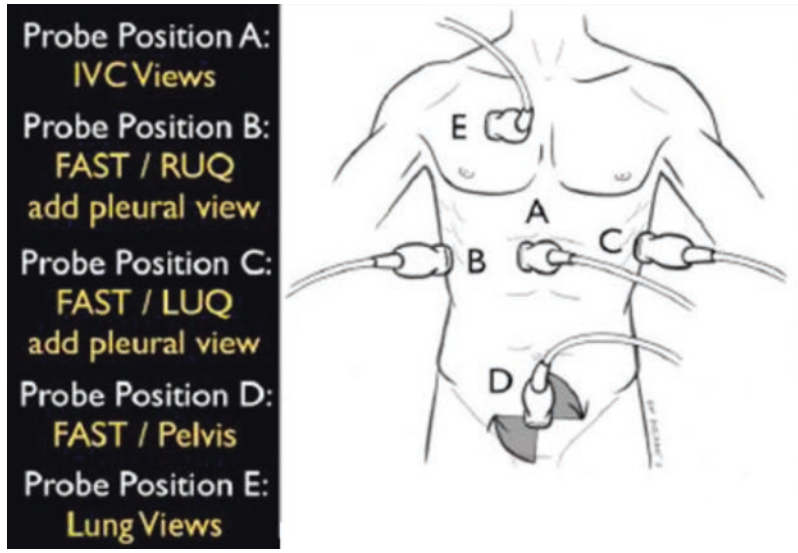

Fig. 44.17 Rush exam sequence. (Reprinted from Seif et al. [9]. With permission from Creative Commons License 3.0: https://creativecommons.org/licenses/by/3.0/)

RUSH exam	Hypovolemic shock	Cardiogenic shock	Obstructive shock	Distributive shock
Pump	Hypercontractile heart Small heart size	Hypocontractile heart Dilated heart size	Pericardial effusion, RV strain Hypercontractile heart	Hypercontractile heart (early sepsis) Hypocontractile heart (late sepsis)
Tank	Flat IVC Flat IJV Peritoneal fluid Pleural fluid	Distended IVC Distended IJV Lung rockets Pleural effusions, ascites	Distended IVC Distended IJV Absent lung sliding (PTX)	Normal/small IVC Normal/small IJV Pleural fluid (empyema) Peritoneal fluid (peritonitis)
Pipes	AAA Aortic dissection	Normal	DVT	Normal

Fig. 44.18 RUSH exam differential diagnoses. (Reprinted from Seif et al. [9]. With permission from Creative Commons License 3.0: https://creativecommons.org/licenses/by/3.0/)

Figs. 44.17 and 44.18. This is useful in rapid detection of shock type.

CPT Coding

Coding for bedside ultrasound has specific requirements to be accurate and often are not captured due to the many points needed to be compliant. Requirements include the indication of medical necessity, anatomic location evalu-

Fig. 44.19 Coding

Ultrasound Type	CPT code	Description	Fees (Total)
TTE	93306	TTE with 2-D, M-mode, Doppler and color flow, complete	$509.19
TTE	93307	TTE with 2-D, M-mode, without Doppler or color flow	$336.93
TTE	93308	TTE with 2-D, M-mode, follow-up or limited	$152.22

ated, and uploaded images. Furthermore, interpretation of the report needs to be recorded in the medical record [17, 18].

Be aware of the many types of ultrasounds and their documentation requirements. As technology advances and portable devices become more available, more ultrasound scans will be performed, and a record of the evaluation provides a more detailed description of the decisions for care (Fig. 44.19).

Summary

The ultrasound tool is only as good as its user. Practice is required for obtaining the appropriate images and diagnostic views and comfort with using the machine. Every patient presents as a different challenge in diagnostic differential formation. The ultrasound tool is a useful, available, portable, cost-effective, and overall effective method to accurately diagnose and appropriate care. Critical care ultrasound is an exceptional weapon in the war against illness in the ICU.

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Additional Resources

SonoSupport Application- Special thanks to Dr. Teresa Wu and Dr. Nicolas Hatch from www.SonoSupport.com for images and figures provided for this text.

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