Matthew Martin
Alec Beekley *Editors*

Front Line Surgery

A Practical Approach

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Top Ten Combat Trauma Lessons

1. Patients die in the ER, and
2. Patients die in the CT scanner;
3. Therefore, a hypotensive trauma patient belongs in the operating room ASAP.
4. Most blown up or shot patients need blood products, not crystalloid. Avoid trying "hypotensive resuscitation" – it's for civilian trauma.
5. For mangled extremities and amputations, one code red (4 PRBC + 2 FFP) per extremity, started as soon as they arrive.
6. Patients in extremis will code during rapid sequence intubation, be prepared, and intubate these patients in the OR (not in the ER) whenever possible.
7. This hospital can go from empty to full in a matter of hours; don't be lulled by the slow periods.
8. The name of the game here is not continuity of care, it is throughput. If the ICU or wards are full, you are mission incapable.
9. MASCALs live or die by proper triage and prioritization – starting at the door and including which X-rays to get, labs, and disposition.
10. No Personal Projects!!! They clog the system, waste resources, and anger others. See #8 above.

Reprinted from "The Volume of Experience (January 2008 edition)", a document written and continuously updated by U.S. Army trauma surgeons working at the Ibn Sina Hospital, Baghdad, Iraq.

We dedicate this book first to the soldier, those "rough" men and women who always stand ready to put life and limb at risk to protect and defend their families, friends, and homeland. We dedicate it to the countless soldiers and civilians who have made it their life's mission to provide comfort and care during times of war, and who have trained others to carry on this sacred mission.

We dedicate it to the most important assets of the soldier at war – the spouses, children, parents, family, and friends who give us the will to carry on and a reason to come home. This book would not have been possible without the two most important people in our Chain of Command: our wives, Becky and Melodie. In the "fog of war" they serve as a constant reminder that strength, grace, and beauty still exist.

Finally, we dedicate this book on combat surgery to our surgical comrades who have made the ultimate sacrifice in the current conflicts in Iraq and Afghanistan: to Lieutenant Colonel Mark Taylor, MD, killed in action in Fallujah, Iraq in 2004; to Colonel Brian Allgood, MD, killed in action in Baghdad, Iraq in 2007; and to Major John Pryor, MD, killed in action in Mosul, Iraq in 2008. A common uniting factor among these heroes was their dedication as both surgeons and as teachers. We pray that their spirit is reflected in this effort to pass on lessons learned from the current front line combat experiences. These lessons have come at too high a price to ever allow them to fade or be forgotten.

"Who kept the faith and fought the fight;
The glory theirs, the duty ours."

~Wallace Bruce

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Any and all author or editor proceeds from the sale of this book are being donated to the Intrepid Fallen Heroes Fund (New York, NY) to support their outstanding work with our wounded warriors.

Preface

As you step off the plane you are struck by an oppressive heat, but this is not what catches your attention. It is the foreignness of this place – the unfamiliar terrain, the noise, the oddly clustered tents and buildings, the serious and determined looks of people involved in a war. I had completed a trauma fellowship at one of the busiest penetrating trauma centers in the U.S. and thought I was ready for anything; mistake number one. Fortunately you have at least several days of overlap with the outgoing group of surgeons that you are replacing.

I first met the surgeon I was replacing in a dusty tent in Tikrit, Iraq. Luckily for me it was Marty Schreiber, one of the best trauma surgeons I know. His last and most important task at the end of his combat tour was to pass on everything a new and inexperienced combat surgeon needed to know to survive and thrive in this environment. Over the next 72 hours I received a mini-fellowship in forward medicine and combat trauma surgery. After that, the first month was an eye opening crash course in how to manage a constant stream of the most severely injured patients you will ever see. I had plenty of tough cases, difficult decisions, and rookie mistakes. I distinctly remember thinking that if it was this tough for someone coming right out of a 2-year trauma and critical care fellowship, how much harder was it for a newly graduated resident or even an experienced surgeon who had not done any trauma for years? This was the initial seed of inspiration for creating "Front Line Surgery".

My goal was to create the book that I wish someone had handed to me before I deployed. To formalize and expand upon the informal "pass-on" sessions that occur every time a new group of surgeons arrives. No basic science, no extensive reference lists; just practical information, techniques, and lessons learned. Each chapter of this book is written by an expert in their field who has also "been there and done that" in a combat theater. I could not have hoped for a better group of authors and colleagues, and have learned a great deal more about combat trauma just from reviewing their chapters. I hope you enjoy it, find it useful, and continue the tradition of passing on these lessons learned to those who follow.

Tacoma, WA Matthew Martin

Of the first five casualties I treated in Iraq in 2004 after joining my forward surgical team, two died and one lost his leg. Four of these casualties arrived at the same time. Their wounds were appalling. One casualty had been blown out of the HUMMV turret, ruptured every solid organ in his body, and broke both his legs. Another had a head injury, impending airway loss, flail chest, ruptured thoracic aortic arch, ruptured spleen, and open femur and tib-fib fractures. We had a total of only 20 units of blood. For a two-surgeon forward surgical team, it was a humbling and overwhelming experience.

The next day I met John Holcomb for the first time as he visited all the surgical units in theater as Trauma Consultant to the Surgeon General. After I discussed the mass casualty from the day before – and it WAS a mascal for our unit – he encouraged us to continue to collect our experiences, write them up, and pass them on. He reminded me that not so long ago another Army major had written up his life-changing experiences treating casualties in Somalia.

We set out to create a book that would provide any deployed surgeon with a well- organized, easy-to-read reference to get or keep them out of trouble. The lessons are not theoretical – they are experience-driven and relevant to any surgeon caring for trauma patients. The chapters are written as if you are having a conversation with a colleague in a trauma bay, across the OR table, or in a bunker. The authors come from diverse backgrounds and many are considered experts in areas other than trauma. However, they all have in common extensive experience treating combat casualties and share passion and commitment to research and teaching. This will be evident when you read the chapters, and I suspect you will find the lessons and insights applicable to the care of trauma patients in any setting. The authors also share a common inspiration – the combat wounded U.S. servicemen and women who they have had the honor to treat.

Tacoma, WA Alec Beekley

Foreword

We admire, honor, and cherish our Wounded Warriors.

We also love them.

They are our Brothers and Sisters, our Sons and Daughters, our next door neighbors. We love them because they have volunteered to put themselves in harm's way and risk all that they hold dear to protect all of us. We love them because they have courage – courage for all to see in the Wounded Warrior with a prosthetic limb or overcoming a physical challenge brought on by the enemies of freedom. Wounded Warriors are a tangible representation of the courage not only within themselves but of all of our service Men and Women.

Therefore, it is our duty – a sacred honor – to make sure that all of us who care for Wounded Warriors bring the best care possible to the battlefield. To ensure that we offer the maximal opportunity for our Warriors to first live and then recover function after wounding.

This book is an effort to pass on lessons learned from taking care of unique injuries that medical personnel will hopefully rarely see in civilian practice.

While most civilian trauma centers see 15-30% penetrating trauma, approximately 90% of combat injuries are from a penetrating mechanism. In civilian trauma explosions account for none of these injuries but the deployed surgeon will see over two thirds of penetrating injuries from a variety of explosive sources. Combat injuries often include combinations of severe multi-system injury; thermal burns, fragmentation wounds, and traumatic amputations.

We must document the lessons learned from our experiences with these wounds that have no true civilian surrogate so that we can pass them on to future surgeons and to each other.

Our Wounded Warriors will not let us down – and we, in turn must never let them down.

This book is a first step in ensuring that we do not.

COL Lorne H. Blackbourne, MD, FACS
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Chapter 1
Prehospital and Enroute Care

Ian Wedmore

Deployment Experience:

Ian Wedmore Provided prehospital care while deployed as part of a number of Task Forces during OEF in 2001, 2002, 2006, 2009 and OIF in 2003, 2004 and 2005.

BLUF Box (Bottom Line Up Front)

1. On the modern battlefield, the top three causes of death that the pre-hospital provider can prevent are extremity hemorrhage, tension pneumothorax, and airway loss.
2. Use of the mnemonics "CAB" or more preferably "MARCH" can ensure that all pre-hospital combat casualty provider tasks are accomplished.
3. Frequent training, both pre-deployment and in-theater, can minimize provider stress and maximize success in real world scenarios.
4. Tourniquets work; use them. Ensure hemorrhage is stopped AND distal pulse is eradicated. If initial tourniquet is inadequate, add a second proximal to the first.
5. Three and a half inch 14 gauge angiocatheters are now standard for needle decompression of tension pneumothorax.
6. If standard endotracheal intubation isn't working, move on. Use the airway with which you are most familiar.
7. Hemostatic dressings (i.e. Combat Gauze) are effective and superior to standard gauze, particularly for bleeding cavitary wounds: Use Them!
8. Hypothermia management should start in the pre-hospital setting; the Hypothermia Prevention and Management Kit (HPMK)™ works.
9. Minimize any non-lifesaving interventions that will delay transport to a facility with surgical capabilities, they waste time and lives.

"The fate of the wounded lays with those who apply the first dressing."

COL Nicholas Senn

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Prehospital and enroute care of a casualty can have a significant effect on both mortality and morbidity. The goal of a prehospital provider is to do whatever is possible to mitigate both of these outcomes. When reviewing the causes of death from the Vietnam War through Operations Enduring and Iraqi Freedom we see little change. The most common causes of death are: torso injury 35%, killed in action (KIA) from CNS injury 31%, Multi System Organ Failure (MSOF) 12%, extremity hemorrhage 9%, tension pneumothorax 5%, and airway 1%.

The most common cause of PREVENTABLE death on the battlefield is bleeding, followed by tension pneumothorax. These are the areas that a front line provider can influence and are therefore the reason that so much effort has been spent on prehospital and particularly Tactical Combat Casualty Care (TCCC) development and instruction. Although not an immediate cause of death, hypothermia has a critical effect on survivability both acutely and in the later incidence of MSOF. The first responders can greatly affect a patient's survival by taking steps to prevent hypothermia from the time of initial injury. The efficacy of TCCC has recently been demonstrated in the retrospective case analysis of several special operations units which found no instances of preventable prehospital deaths within those units once TCCC was fully utilized.

Critical Tasks and Priorities

Critical tasks for a first responder involve addressing all of the potentially treatable causes of mortality. While standard civilian priority has been based on the ABCs, the present approach to combat trauma by military providers makes control of significant hemorrhage a first priority rather than airway issues. This is based on the fact that you can bleed out faster from an arterial injury than an airway issue can kill you. This is a paradox that is rarely ever encountered in civilian trauma care.

In all cases you must first control any life-threatening hemorrhage. This is done with either a tourniquet if an extremity is involved or a hemostatic agent and pressure dressing on an area not amenable to a tourniquet, such as the chest, abdomen, buttock, neck, axilla or high groin. The current conflicts have demonstrated the incredible impact of the simple extremity tourniquet, and you should familiarize yourself with the devices currently being used. Unfortunately we do not have so simple a solution for the control of non-compressible hemorrhage, which is now the number one potentially preventable killer on the battlefield. Once hemorrhage control has been addressed, the airway is the next priority; this will be discussed in more detail later. Breathing issues are treated third, with occlusion of chest wounds and needle decompression of suspected tension pneumothorax. Use them liberally, no one has died from a thoracic needle but many have died of a tension pneumothorax without them.

The secondary survey is then undertaken with consideration of all wounds, hypothermia prevention, pain control and use of antibiotics. As opposed to the civilian ATLS approach mnemonic of "**ABC**" the TCCC approach to combat care is described by the mnemonic "**CAB**".

CAB

Circulation: Control arterial bleeding with a tourniquet or hemostatic agent and wound packing in areas not amenable to a tourniquet.

Airway: Treat airway issues.

Breathing: Seal chest wounds and treat tension pneumothorax.

A slightly different approach is taken by some special operations forces and several NATO countries, who utilize the mnemonic "**MARCH**" to give the appropriate, prioritized approach to casualties. This approach is more logical and utilitarian as it addresses everything the prehospital provider can do to treat a casualty, though either method will work.

MARCH

Massive hemorrhage – place tourniquet, or hemostatic agent in area that a tourniquet cannot be used.

Airway – control with simple technique vs. cricothyroidotomy vs. supraglottic airway or intubation.

Respiration – seal chest wound and decompress if needed

Circulation – place IV access, utilize intra-osseus access if needed, and utilize hypotensive resuscitation. WITHOLD fluids if awake, mentating, and palpable radial pulse.

Hypothermia – Put the patient in an HPMK™ (Hypothermia Prevention and Management Kit™) or "burrito" wrap.

Psychology of Prehospital Care

The combat prehospital environment is often well outside the comfort zone of most providers and even trained civilian medics. The battlefield is dirty, chaotic, and dangerous with prehospital care often being delivered under adverse conditions or hostile fire (Fig. 1.1). As such, one may have initial difficulty in applying what one actually knows. While the knowledge of what to do has been learned, it has often never been practiced and it is therefore not uncommon, at least initially, for one to "vapor lock" with the first prehospital exposure to the injured individual. This can be minimized through the use of repetitive prehospital training utilizing simulations and animal models. Practice drills immediately on arrival in theater can help in this regard as well. When this has not been possible, the best advice is to narrow the thought process to **MARCH** and concentrate on following it. This will ensure the critical tasks are accomplished. You may have medics assigned to your unit or in close contact with your facility; many of them young and inexperienced. Share your knowledge and experience with them; training them as hard and as realistically as possible may save both their lives and that of their patients.

Fig. 1.1 Images from prehospital care and evacuation in combat operations. (**a**) prehospital care being initiated while simultaneously returning hostile fire, (**b**) casualty awaiting helicopter evacuation in a dirty and dusty environment, and (**c**) helicopter evacuation from a rooftop in mountainous terrain

Some Important Considerations for Treatment

Tourniquets (Fig. 1.2)

Tourniquet use is now the standard for the military, and placement of tourniquets in the prehospital setting has been shown to decrease mortality 23% as compared to Emergency Department placement. They are the best initial choice for controlling

Fig. 1.2 Extremity tourniquets on combat wounds. (**a**) Special operations forces tactical tourniquet (SOFT-T) correctly positioned on a mangled extremity. (**b**) Combat application tourniquet (CAT-1) placed by prehospital personnel on combat casualty with bilateral below knee traumatic amputations, full hemorrhage control provided for transport. Tourniquet can be placed and adjusted with one hand by the casualty if necessary

severe bleeding from an extremity. Do not use hemostatic dressings for the initial control of significant bleeding on an extremity. Place a tourniquet; control the bleeding; then during the secondary survey wounds can be specifically addressed. At this point the placement of a hemostatic dressing and bandage on an extremity can be tried and, if effective, then you can remove the tourniquet. You do not want to be losing blood initially while trying to get a good dressing in place; the prehospital provider strives to save the loss of every possible drop of blood! In combined cases of abdominal/chest penetrating injury and extremity hemorrhage, leave the tourniquet in place until the non-compressible injury is fixed.

Tourniquets must be placed with enough force to completely occlude the pulse if one is palpable distally. Failure to do so and apply only enough force to occlude venous flow can actually increase bleeding through a venous tourniquet effect. In the hypotensive individual with no distal pulse, crank the tourniquet up tight and be prepared to tighten it more as the casualty is resuscitated. If the initial tourniquet does not stop bleeding, place a second one proximal to the first. There have been rare problems reported with efficacy of a tourniquet on the forearm and tibia/fibula. If a tourniquet placed in these areas is ineffective then another should be placed proximally. The time of placement of a tourniquet should be noted in several locations: on the casualty as well as on the tourniquet (the new combat action tourniquets (CAT-1) have a location for this).

Thoracic Needle Decompression

Needle thoracentesis of tension pneumothorax has several pitfalls. The most common problem with decompression is failure to reach the pleural cavity. This is the reason 3½ in. 14 gauge catheters over a needle are now the Army standard. Another common issue that could lead to morbidity is placement of the needle too medially. It should be placed lateral to the mid-clavicular line, not medial to it. In cases of very large-chested individuals, the decompression can be attempted in the 5th intercostal space, mid-axillary line (the standard chest tube spot).

Airway Treatment

Airway treatment usually requires either simple airway maneuvers or will require a surgical airway. In the data from Vietnam, airway compromise only represented 1% of preventable deaths. While this percentage increased to 11% in the small case series of SOF deaths in OEF/OIF, this study had a very small number of patients. This study's percentage may not represent the true percentage of casualties with airway compromise. Indeed, the last few years since this study was published seem to suggest that airway issues do actually represent only a small percentage of salvageable patients.

For most airway issues, patient positioning and the use of a nasal trumpet will be all that is required. When a more advanced airway is required, it is usually due to a head injury (with or without significant facial trauma) or burns with inhalational injury.

A head injury without facial trauma is the most common occasion you would want to use a supraglottic airway adjunct or perform intubation. One concern voiced with supraglottic airways (King LT, Combitube, LMA) is that they do not provide any airway protection from aspiration. This is a propagated falsehood. In all cases they provide some protection from aspiration and in many cases have been shown to provide nearly equivalent aspiration protection to endotracheal intubation, depending on the device. Concern for aspiration protection should not preclude the use a supraglottic airway in a patient who needs it, particularly in those who are not skilled in intubation. Don't let a patient die with an airway issue because you were afraid to put in a supraglottic device and instead tried several ineffective intubation attempts. **Use the airway that is most effective and with which you are most familiar**.

Head injury with facial trauma or facial trauma with airway issues alone will often require a cricothyroidotomy (Cric). This procedure can be performed with limited morbidity if one is trained. Crics should be practiced at every available opportunity, particularly when animal models are available. There is no simulator yet available that provides training similar to performing an actual cric. Special Forces medics who practice crics constantly have found that they can provide a definitive airway *in less than 1 min even when under fire*. A tracheal hook has been found to be essential for easing the difficulty of this procedure. The actual utility of the many cric kits available for use is unclear. The vast majority of crics actually performed in theater have been done with a #11 blade and a tracheal hook. What exact technique one uses is not important provided you have practiced it. Any adequately sized tube can be placed through the cricothyroid membrane to secure the airway, most commonly a small (6 or 7) cuffed endotracheal tube. **Make sure you secure this tube well or it will dislodge, usually at the worst possible time**.

In cases of facial trauma with bleeding, make sure you do something to protect the airway early, be it a supraglottic device, intubation if you are skilled at it, or a cric. The airway will become an issue if not addressed early. All burns with the potential for inhalational injury should also have a definitive airway placed early. A patient with burns and inhalation injury is the one case where you will need to go to intubation as soon as possible, as the supraglottic airways will not be effective as the airway becomes edematous and obstructed. In the case of a burn with long transport and inability to intubate, go to the cric.

IV Fluids for Resuscitation

It is now accepted that low volume resuscitation is the standard in combat injuries with non-compressible hemorrhage. While ATLS still teaches full resuscitation with IV fluids in most cases, it now also provides for the provision of low volume resuscitation (also called hypotensive or hypovolemic resuscitation). Casualties with penetrating wounds of the abdomen or chest may have non-compressible hemorrhage.

In these cases resuscitation is minimized until definitive surgical care occurs. The goal is to provide enough resuscitation to prevent the onset of irreversible shock, and yet at the same time not increase blood pressure to the point where a forming clot is “blown off,” thereby increasing bleeding. Rebleeding seems to occur at a systolic pressure above 85–90 mmHg, so this is the resuscitation goal for which to aim, but not higher. Thus in a hypotensive patient, intravenous fluid is given until this target BP of 85–90 mm is reached. Clinically (when no BP cuff is available) this is noted as the presence of a radial pulse and normal mental status. When this point is reached IV fluids are slowed to TKO unless the pressure drops again. The goal is to not overshoot this target blood pressure and cause increased bleeding.

Resuscitation Fluid Choice

Most often, your choice of initial resuscitation fluid in the prehospital situation should be none, and the patient can be heplocked until hospital arrival. The choice of initial resuscitation with crystalloid vs. colloid in the combat prehospital setting is most often determined by its weight and size rather than by any science. At the present time, literature does not show a definitive advantage of one over another fluid type in the prehospital settings. The ideal fluid for prehospital resuscitation in combat should have the following properties: excellent volume expansion, lightweight and easily carried, durable packaging, and no adverse inflammatory or coagulation effects. The fluids that currently come closest to meeting these criteria are the hypertonic crystalloids (i.e. 3–7% saline) and colloid products, and have been recommended by several expert panels on combat fluid resuscitation.

Colloids or hypertonic saline are more commonly used in the prehospital setting when fluid must be borne on foot. This is because 1,000 cc of lactated ringers will result in only about 200–250 cc remaining in the intravascular space after its quick initial redistribution. Hetastarch, if given as a 500 cc bolus, results in 500–600 cc in the intravascular space as the colloid pulls fluid into this space. The literature to date also does not suggest any issue with giving a colloid to a dehydrated individual. The present TCCC recommends the colloid solution hextend. Hextend is hetastarch in a lactated ringer’s solution. While hetastarch can inhibit platelet function, this is not an issue until approximately 1,500 cc have been given in a normal sized individual. Hence, a maximum dose of 1,000 cc of hextend is recommended by TCCC. Hypertonic saline has been recommended by the Institute of Medicine and several other expert panels. It provides excellent volume expansion with no coagulopathic effect, has a better inflammatory profile than standard crystalloid, and is also effective at lowering intra-cranial pressure in brain-injured patients. It should be given as a 100–250 cc bolus with repeat dosing as needed. Although serum sodium levels should be followed closely after administration, it has an excellent safety profile and the resultant hypernatremia is well tolerated and potentially even beneficial.

En Route Considerations

There are several considerations prior to transport of a casualty and enroute. Secure the patient, the IV, the airway, and the tourniquet. They will come loose! You cannot do much on a helicopter! It is loud, constricted, and cold. At night you will have very little light available as most often you are flying under blackout conditions and cannot use white light which interferes with the pilot's night vision. A ground vehicle or ambulance, while less so, is also a difficult environment to work in. Anticipation and prevention are the keys to successful and safe patient transport.

Secure the Patient

It seems axiomatic, but the frequency with which casualties are not secured in the transport vehicle is surprising. Perusal of the civilian literature reveals that the incidence in well-trained prehospital providers have been noted to be as high as 30%. In all cases the casualties should be secured to the stretcher, Skedco™, or whatever device they are being transported on. If the transport time is short and a tourniquet was placed, strongly consider leaving it on and in place. If bleeding has stopped prior to transport and it will be delayed, release the tourniquet but keep it in place so it can be reapplied in seconds. In a hypotensive patient with extremity wounds that are not bleeding consider placing a non-tightened tourniquet, so if bleeding starts during transport it can be cranked up immediately.

Airway

Secure the airway!! While there are numerous devices out there to do so, none have been shown to be the best. Tape never works on its own – use it only to backup something else. Triple secure it. Make sure if you are using oxygen you have twice as much as you will need for the transport. While most casualties don't need oxygen, to run out during transport in those who do is an irretrievable error.

Be Wary of the IV Drip

A bag will either stop working or will empty rapidly, which may not be what you want with low volume resuscitation. I have seen an individual with a chest wound who arrived hypotensive (SBP 80) and who initially put out only 150 cc of blood with chest tube placement at a level II facility subsequently lose over 1,000 cc from the chest tube when his IVs were inadvertently opened wide during helicopter transport. His BP increased to over 100 systolic with the above increase in bleeding. If you have a good working lines secure it very well and heparin lock any other lines. Excess lines pull, yank, or may give too much IV fluid.

Wound Dressing

Dress all wounds before transport. Even small wounds may begin to bleed if a hypotensive patient becomes resuscitated just prior to or during transport. Apply a hemostatic dressing to any bleeding wounds and wrap securely. For cavitary wounds, pack the wound with a hemostatic dressing (i.e. Combat Gauze) and apply a pressure dressing or manually hold pressure.

Chest Decompression

A needle decompressed chest may have the catheter kink during movement and transport. Keep an eye on the casualty and be prepared to decompress again. This is a place where on long transports a “decompression extender” such as an Urosil or other small gauge chest tube may have utility.

Hypothermia Prevention

Prevention of hypothermia is crucial during transport. The air mass moving over a patient in flight causes significant convective heat loss even at high ambient temperatures. Remember this is one of the ways we cool patients in the ED, by fanning warm air over them!

The HPMKs™ work (Fig. 1.3). Use them for initial evacuation after injury, or whenever you are transporting patients between facilities. Open the heater element

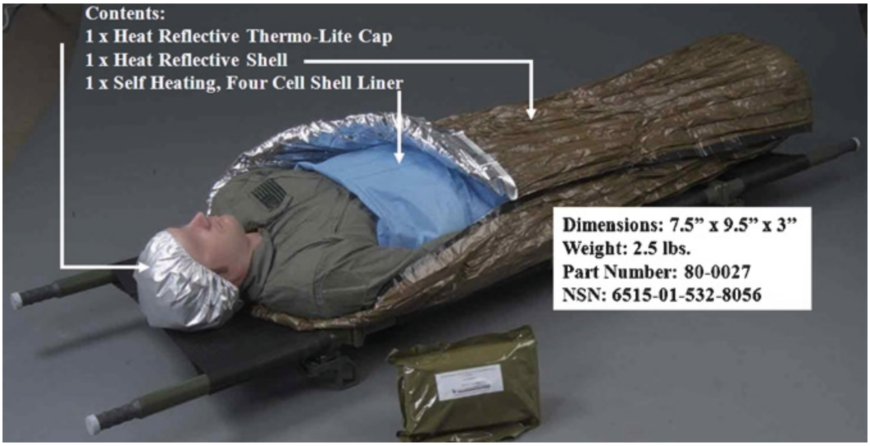

Fig. 1.3 The currently fielded hypothermia prevention and management kit (HPMK™) provides excellent control of body temperature and prevention of heat loss during medical evacuation or inter-facility transfers

up ahead of time to allow it to "breathe" and activate. It is worth "burning through" heat cells you will not use to ensure you have one that will actually provide some heat. If you don't have an HPMK™, utilize a "burrito" hypothermia wrap using whatever blankets, sheets, etc that you have. Due to the psychological effects as well as the possibility of mis-triaging a casualty, **do not utilize actual body bags**.

General Considerations

There are a number of general considerations for prehospital care.

Chest Seals

There is still not a great chest seal available for pre-hospital treatment of open pneumothorax. Wipe and clean the chest as best as possible before using one. Do not let them dry out during storage, because they don't work as well. The original Asherman Chest seal, because of its poor adhesive, is basically worthless. This device would never stick to the chest of an actual casualty. The newer Asherman chest seal with the new military grade adhesive, as well as the newer chest seals such as the Bolin, HALO, Hyfin, H and H, and EOD grade hydrogel all have supporters and detractors. At the present time no one can be recommended over any other. In all cases, one side does not need to be left open. If respiratory distress develops, you will needle decompress the chest or place a chest tube.

Hemostatic Dressings (Fig. 1.4)

The efficacy of all hemostatic agents previously and presently used has been great in animal studies, while in actual combat/patient use the efficacy has been variable. Hemostatic dressings can be broken down into generations of development. The first generation was the dry fibrin dressing which is no longer available. The second generation dressings are the original QuikClot powder and QuikClot sponge, the Hemcon chitosan bandage and chitoflex dressings, and Celox powder. All work in the right circumstances, all have good and bad anecdotal reports, and both Hemcon and QuikClot have human/combat case series of success. The original QuikClot powder has the problem of being painful and causing burns ranging from mild to severe. The original Hemcon works primarily through "sealing of a wound" and needs to be cut to a size that will allow it to seal the wound. Chitoflex is designed to be packed into a wound. This should be done quickly as it has been found to stick to the gloved hands if done in a slow methodic fashion.

The top choices at present are the third generation of agents. Combat Gauze, Celox Gauze, Chitogauze and possibly Traumastat. The current TCCC recommendation

Fig. 1.4 Topical second (*top row*) and third generation (*bottom row*) hemostatic dressings. *Clockwise from top left*; (**a**) Hemcon chitosan wafer dressing, (**b**) QuikClot crystal zeolite powder, (**c**) Combat Gauze kaolin impregnated roll, and (**d**) Chitoflex dual-sided Chitosan roll dressing

based on available data is to use Combat Gauze, a gauze roll treated with kaolin. While a recommendation for treatment when Combat Gauze is not available is not specifically addressed by TCCC, we recommend you use whatever other third generation agent you have. If you don't have any third generation bandages use a second generation agent. You should also consider the type of wound that you are dealing with and whether it would be more amenable to a bandage-type dressing, a gauze-type dressing, or a topical powder. Whatever agent is used you should then cover it with a standard pressure dressing. Do not place the hemostatic agent and expect it to remain in place without a pressure dressing. Apply it and only remove and/or examine if it appears bleeding is continuing through it and the pressure dressing.

Chest Tubes

There appears to be little support for the placement of chest tubes in the prehospital environment. Needle decompression will treat a tension pneumothorax. A simple pneumothorax will not kill someone. The lung will neither re-expand nor provide tamponade for pulmonary bleeding without added external suction. A chest tube placed in a dirty chaotic environment increases the likelihood of infection and improper placement. The time to consider prehospital chest tube placement would be in those cases where you will have a patient for a very prolonged time before they can be transported to a medical site with surgical capability. Present animal studies support the efficacy of needle decompression alone for up to 4 h.

Prehospital chest tubes or needle decompression extenders should be considered in cases where: evacuation is significantly delayed or will be extremely prolonged, in cases where needle decompression is ineffective despite multiple attempts, or when catheters recurrently clog or kink. Needle decompression extenders are smaller-sized devices used in lieu of a needle decompression or full-size chest tube. The Urosil, an 11 French trocar-placed device (FDA-approved for treatment of spontaneous PTX), has been used by at least one SOF unit. One allied country reports using neonatal chest tubes. The experience with these devices is limited, but theoretically they would be much more stable than a 14 gauge decompression catheter. All of these prehospital devices would be expected to be replaced with a true chest tube when the patient reaches definitive care.

Pre-hospital Antibiotics

All combat wounds are inherently dirty, and while not replacing the requirement for adequate irrigation and cleaning, the provision of antibiotics early after wounding may improve ultimate outcome. TCCC presently recommends the provision of antibiotics if a casualty will be held for greater than 4 h. However many special operations units are giving oral antibiotics to any casualty who can take them shortly after wounding regardless of the time to transport. This inherently makes sense and more importantly there does not seem to be any evidence of a downside to this (such as increased antibiotic resistance). Based on this thought process, prehospital antibiotics may be given orally if the patient is conscious and does not have an abdominal wound. This is accomplished at present with the inclusion of antibiotics in the "combat pill pack" carried by some units. The antibiotic carried in the packs presently is moxifloxacin. This is an ideal agent, as quinolones are 99% bio-available orally, have a very low incidence of allergy, and cover the standard bacteria initially encountered in wounds. In cases where an individual cannot take oral agents, IV antibiotics can be given if time allows. Do not delay transport to do so.

Pain Control

Pain control should be given if at all possible to all casualties. As mentioned, combat wound pill packs are being utilized by some units. For pain control these contain 1,000 mg of Tylenol and a 15 mg dose of meloxicam. Meloxicam is a predominantly Cox-2 non-steroidal anti-inflammatory drug so it does not affect platelet function. If a wounded soldier can take something by mouth, he opens the pill pack and takes all the medications. This provides some immediate pain relief without any negative effect on the CNS. This can enable the soldier to either continue the mission or at least aid in his care.

Narcotics remain the mainstay for significant pain relief. While IV and IM morphine are well-known and utilized, their use has been supplemented and superseded in some cases by the use of Oral Transmucosal Fentanyl Citrate (OTFC). The use of OTFC has become standard in SOF for those who can swallow and are conscious. Common side effects seen with the use of OTFC include nausea and pruritis, (up to 30 and 15% incidence in some studies). For this reason, ondansetron oral dissolving tablets are often routinely given with the OTFC lozenge. Experience to date indicates that 800 mcg is usually needed to help with pain. This can be given as a 400 mcg lozenge repeated ×1 or as a single 800 mcg. An example of OTFC use from early OIF:

> Nine patients required care for extremity fractures simultaneously. Due to the tactical situation, the placement of IVs was, at best, difficult. Of the nine patients, seven had significant fractures and all had significant pain. All were given OTFC with 90% plus reduction in pain within 15 minutes. Several fell asleep but maintained airway reflexes and oxygen saturation. Two, however, fell asleep with the "lollipop stick" hanging out of their mouth.

Based on this episode and similar experiences, it is recommended that the lozenges should be taped to the finger of the user in the event the individual becomes somnolent.

Ketamine

Another agent to consider utilizing is low dose ketamine. It is effective at pain control in doses much lower than that utilized for sedation. The usual dose used for pain is 0.1–0.2 mg/Kg titrated to effect. It is an ideal agent as it protects airway reflexes and has a huge therapeutic window. While not specifically studied, its use for pain control should be avoided in those with head and ocular injuries. Those given ketamine should have weapons removed from them due to its dissociative affects.

Recombinant Factor VIIa

The prehospital use of recombinant factor VIIa has been advocated by some, and in at least one case utilized, but this is only by very highly trained individuals with intimate knowledge of factor VIIa. There is not yet a definitive protocol that balances the benefits vs. the risks of prehospital factor VIIa. The determination of when it has benefit in the prehospital setting requires significant experience and training and its use is not recommended for most prehospital providers.

There are some considerations with factor VII storage and transport. Previously factor VII was considered to require refrigeration; however, the new shelf-stable version is good if maintained at room temperature. Even with the original factor VII, prior to reconstitution it would maintain decreasing efficacy for up to 72 h after it had been removed from refrigeration. The hotter it is, the quicker it degrades. Possibly, the sooner after wounding the factor VII is given the more efficacious it is, as it does not work well at all in an acidotic or thrombocytopenic patient. Its efficacy is not readily affected by hypothermia, at least down to a core temperature of 28°C.

Prehospital Blood and Plasma

Neither blood nor plasma are utilized routinely in the prehospital environment due to the storage requirements. In limited cases where a casualty has to be held for a prolonged period of time (weathered out at a CCP in the Afghanistan mountains), there is benefit to having blood and plasma available. In pre-planned circumstances, several devices are currently available for appropriate short term storage of blood products. In these cases, a plan for warming and thawing must be generated. In situations that are unplanned, the best option would be to provide whole blood. For this reason transfusion sets should be available and whole blood donation and transfusion practiced!! Literature to date shows no cases of severe transfusion reaction when whole blood use is matched based solely on dog tag data. Whole blood offers the advantage of giving oxygen carrying capacity, clotting factors, and warmth to the casualty, though at the slightly increased risk of a blood-borne infection.

One of the most promising areas of current research that will likely translate to battlefield use involves blood product preparations that are suitable for forward use. This involves processing and packaging that eliminates the need for refrigerated or special storage while preserving function and bioactivity. Lyophilized or "freeze-dried" plasma products are now in advanced testing, and have been demonstrated to be safe, easy to reconstitute, and retain full coagulation factor activity compared to stored products. Work is also in progress on similar red cell and platelet products. The future combat medic will very likely have some of these or newer products at his disposal, which will greatly improve the ability to carry the concept of "Damage Control Resuscitation" to the prehospital combat or disaster environment.

Summary

There is much the prehospital provider can do to both save the life of those injured in combat as well as decreasing the morbidity of those injured. The priority of treatment is: (1) control of hemorrhage, (2) airway control, (3) treatment of chest injury, and (4) prevention of hypothermia. Many other considerations also come into play for proper casualty care as have been discussed. You should familiarize yourself with these concepts and practices in order to understand and continue your part in this “chain of survival” for the combat casualty.

Chapter 2
Combat Triage and Mass Casualty Management

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Deployment Experience:

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Jamie C. Riesberg	Team Physician, Combined Joint Special Operations Task Force, Afghanistan, 2008

BLUF Box (Bottom Line Up Front)

1. The Five R's: RESOURCES, REHEARSE, RESPOND, ROUTE, RESET.
2. SECURITY is the foundation of safe and effective care:
   BEST medicine on battlefield is FIRE SUPERIORITY!
   Ensure effective enemy action is ended prior to rushing to treat.
3. Plan BEFORE the casualties arrive; rehearse the Plan to build "muscle memory".
4. Rapidly sort patients with ABCDE sweeps: 2A's – Arterial Hemorrhage + Airway, then B + C, then D + E (15 s).
5. Rapidly reassess every patient for changes or mis-triage.
6. The triage officer (TO) should be one of your most experienced and organized personnel.
7. Triage = provide greatest good for greatest number, NOT "sickest first".
8. Use every resource (blood, x-ray, evacuation, personnel) appropriately.
9. Patient admin personnel and record keeping are essential to MASCAL response.
10. Remember heart and compassion – for victims and for team.

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"In any emergency setting, confusion is a function of the cube of the number of people involved."

Clement A. Hiebert

Introduction

Although much of this book focuses on preparing for combat trauma care at the individual provider level, the most critical training for a UNIT to prepare to handle combat casualties is Triage and Mass Casualty Management. This chapter will share triage and mass casualty expedients from three combat perspectives representing different echelons of care. Every trauma patient triggers a triage or sorting to align available resources with needs. But when those needs surpass apparent resources, we declare a MASCAL or mass casualty and launch a series of rehearsed strategies to achieve the greatest benefit for the most patients. Intensity, number of casualties, and environment all contribute to this overload calculation: a single complex injury patient can eliminate a unit's ability to deliver additional casualty care, and two immediate surgical patients will max out many Level 2 facilities. Medical leaders can hone a unit's trauma-ready posture to expand its ability, as "*chance favors the prepared team*." This chapter reviews the "5-R's" to prepare a team for successful combat trauma response: Resources, Rehearsal, Response, Route, and Reset.

Resources

Security

While security may not seem to be a direct medical responsibility, it is always your concern, since the current asymmetric battlefield entails risk at all echelons of care, from aid station to theater hospital. Ongoing enemy action at the scene will force limited "care under fire" response. Fire superiority can be the "best medicine" until the site is secure, but medical personnel pull triggers only if security elements cannot meet the demands. Avoidable injuries to the medical team can doom its mission. Security forces should quickly assess for catastrophic secondary attacks and establish a safe perimeter for the treatment facility or triage site. If chemical contamination is a risk, a sweep of incoming casualties may be required, but available chemical detectors will slow your triage and treatment process.

Your MASCAL plan should incorporate a thorough plan for providing safety and security to the patients and facility staff. The priorities should be on securing the area, controlling vehicular access, controlling pedestrian access, and assisting with the management of enemy or suspected enemy casualties. Although hospital units have traditionally been off-limits during conventional warfare, they are seen as a high-value target by enemy forces in current combat operations. All unknown vehicles or persons must be verified and searched prior to allowing them access to the facility. Enemy casualties should be searched and secured, even if it does delay care. Controlling access then becomes the most important security function, as people will naturally gravitate to the hospital area when there is a MASCAL situation. Although most are well-intentioned, if you allow access to bystanders and non-essential personnel you will only make an already chaotic situation worse.

Context

The current military casualty triage and evacuation system uses a model of echelons of care with progressively increasing capabilities; from point of injury (Level 1) to Level 5 hospitals in the U.S. (see Table 2.1). Your unit's role in the casualty care continuum in both military and civil contexts will shape its trauma response, whether it is Level 1 unit point of injury care on the forward battlefield, Level 2 life-saving damage control surgery, or Level 3 vascular reconstruction. While not ironclad, Level 1 units are often first responders to civil and military events, with "on-scene care" and care under fire. Level 2 units frequently receive ground and air transported casualties, and Level 3 facilities are geared to receive air-evacuated casualties as "fresh trauma" from point of injury and Level 1 units and as "used trauma" from Level 2 units which have already performed initial life-saving surgical management. Local host nation hospitals may be able to receive and manage wounded national patients in order to augment a unit's MASCAL response.

Trained and Ready Personnel

Medical personnel will benefit from trauma care experience prior to deployment. Advanced Trauma Life Support (ATLS) training is a must, but should be supplemented with additional combat and service specific courses. Since units are often built with personnel who have minimal time together before deployment, common training can accelerate cohesive unit response in theater. Be sure to survey personnel in your unit and on the Base to find capable people "hidden" in other units or in command and staff billets. You can often identify individuals with medical skills beyond their duty titles that can be helpful in MASCAL scenarios. Since many units receive and treat more civilian than military casualties, specialty skill sets such as pediatrics, obstetrics, or burn care can be invaluable.

Culture

Competent cultural assistance is vital in international trauma response. Medically-seasoned interpreters are essential team members at the bedside throughout the triage and treatment process. They play a huge role in shaping culturally sensitive care. Unit members who learn basic local language greetings and health questions can enhance trust and effectiveness in the care of wounded nationals. A capable bicultural

Table 2.1 Military Echelons of care

Echelon of care	Example	Surgical capability	Capabilities	Comment
Level 1	Battalion Aid Station, Shock Trauma Platoon	None	"Aid bag", limited supplies, maybe ultrasound	Medics and PA or Primary Care doc; no hold capability
Level 2	Forward Surgical Team (FST), Air Force Field Surgical Team, Navy Forward Resuscitative Surgical System (FRSS)	Limited	Damage control surgery, basic lab, basic x-ray and ultrasound, oxygen, simple blood FRSS has surgeon, orthopedics, anesthesia, ER, FP or GMO, psych, dental	Patient hold beds, MEDEVAC drops patients here; may be mobile – may divide to send bounding element ahead
Level 3	Combat Support Hospital, Theater Hospital, Hospital Ship	Yes, general and orthopedic surgery, often subspecialties	Multiple specialists, advanced lab and blood product support, advanced radiology and CT, physical therapy	Damage control surgery, more definitive management; stabilization and evacuation portal to Level 4
Level 4	Regional Medical Center (Landstuhl, Germany)	Extensive, excellent subspecialty support	Major medical center capabilities	More definitive surgical intervention; burns may bypass directly to Brooke Burn Center
Level 5	CONUS National Medical Referral Center (Walter Reed, Bethesda, Balboa, Brooke)	Full tertiary care	Full rehabilitation and specialty intervention	Performs most delayed and "reconstructive" care

or host nation medical officer or authority can "sweep" the injured to identify family groupings or key individuals such as high ranking government officials or celebrities. The same liaison can help disposition injured host nationals to national medical providers and facilities if medical personnel have cultivated relationships with them. In Afghanistan, tea with the local hospital director resulted in over 20 rapid patient transfers to his facility during a busy summer month, allowing quicker facility recovery and better support of Coalition operations. In Baghdad, we hosted shared CME for local physicians to build trust in sessions orchestrated by a contracted Iraqi-born civil medical liaison physician. US Marine Forces operating in Al Anbar routinely augmented medical missions in support of local Iraqi physicians, and provided resources, medical supplies, and logistics that their healthcare infrastructure lacked, building trust bonds.

Supply and Transport

Casualty care can consume large volumes of supplies, and resupply will be a major determinant of unit casualty response. Many units develop lists of trauma response supplies and cache them in strategic locations. Be sure to note expiration dates prominently if IV fluids or meds are part of these contingency stores. Define transportation and evacuation resources and routes. Transport options are exquisitely sensitive to tactical situation, terrain, and weather. A dust storm can eliminate rotary wing evacuation of casualties. Stabilization and rapid transport to a higher level of care is the main mission for Level 1 and nonsurgical Level 2 units without patient hold capability or resources to "sit on" casualties. If you depend on rotary wing evacuation, prepare ground evacuation or patient hold contingency plans in case aircraft are grounded.

Rehearsal

Plan

Analyze and plan for the mission, engaging all stakeholders to choreograph a shared response that remains flexible enough to match unique events. (See Fig. 2.1 for simple plan template.) The MASCAL mnemonic (minimize chaos, assess, safety, communication, alert, and lost) is a great starting point and guide (Fig. 2.2). Key considerations include security and protection needs, command and control, communications means and frequencies, casualty collection points (CCP's), medical resupply, litters and straps, and personal protective equipment posture. Landing zones need to be defined with marking devices at the ready, and lights are needed for outdoor night operations. Safe transportation routes into and

MASS CASUALTY PLAN FOR DATE

Unit
Location
Date

References:
- a. MAP 8
- b. Operations Order

Time Zone Used Throughout the Order:

TASK ORGANIZATION: See base order of organization of units.

1. SITUATION: Base units prepared to conduct coordinated emergency medical response operations during tactical and non-tactical disasters.

   A. Enemy Forces. (threat assessment)

2. MISSION: On order, execute MASCAL operations for rapid treatment and evacuation of casualties.

3. EXECUTION:
   - a. All Medical Units – define mission, evacuation, goals
   - b. MASCAL – define, identify declaration authority

   Define execution by 4 Phases of MASCAL Operation:

   Phase 1 - Preparatory phase:
   - Prepare and train
   - Define communications

   Phase 2 - Immediate response and incident notification:
   - First responder care
   - Notify base security element
   - Dispatch incident commander to scene
   - Notify medical units via communications net
   - Dispatch elements for site security, ordnance clearance, crowd and traffic control

   Phase 3 – Coordinate medical response:
   - Provide care at MASCAL site: all casualties triaged, life-saving treatment initiated.
   - Initiate evacuation of urgent and urgent surgical

   Phase 4 – Reception, staging and evacuation:
   - Evacuate and cross-level casualties
   - Document care and accurate reports to ensure 100% accountability of casualties

4. SERVICE SUPPORT: Define units' resupply procedures during and after the event

5. COMMAND AND SIGNAL
   - a. Command - define who is in charge
   - b. Signal – define frequencies, numbers, means of communication

Signed: Commander

Annexes:
- Response maps
- Ground evacuation (NO FLY) Plan if air evacuation cannot be employed
- Notification Matrix (radio, phone tree with frequencies, numbers)
- Responsibility Matrix by unit (geographic area of responsibility or specific role))
- Patient Care Matrix for rules of engagement for host nation casualties, combatants

Fig. 2.1 Template for MASCAL plan

out of the area must be clearly defined, with special attention not to endanger casualties and treatment areas on the ground. Casualties will need to be disarmed, and suspected enemy combatants will need to be appropriately monitored. Many sites modify the Incident Command structure employed in emergency response at many U.S. hospitals, where an overall incident commander directs coordinators with

M – *Minimize chaos* – remain calm and confident

A – *Assess* – perform accurate, ongoing triage;
assess weather, supply status, personnel, etc.

S – *Safety* – do not create additional patients;
Take care of self and staff

C – *Communication* – can never be enough;
Make it clear and concise

A – *Alert* – be ready for more casualties;
Reconstitute and resupply

L – *Lost* – don't lose patients or staff-
Use tracking system for patients,
Maintain accountability of the team

(courtesy of COL Jorge Klajnbart, Chief of Surgery, Evans Army Community Hospital)

Fig. 2.2 MASCAL mnemonic illustrating key points for mass casualty scenario management

specific responsibilities such as triage, treatment teams, security, logistics, public affairs, manpower pool, security, transportation and evacuation.

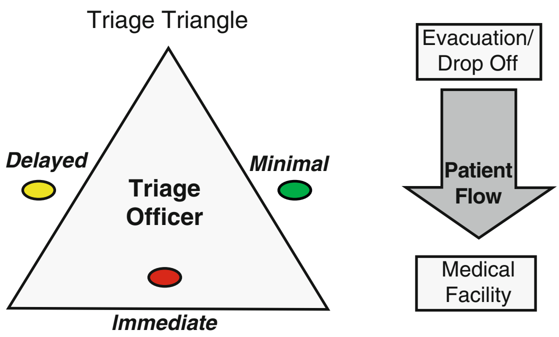
Trauma readiness is a daily preoccupation, particularly tough for units with infrequent trauma and rare opportunities to put plans into practice. Rehearsal of the MASCAL plan with real people in litters or beds during exercises will identify vulnerabilities better than by brainstorm or table top drills. Practice with both continuous patient loads and sudden surges, as the demands are different. Nearly all exercise after-action reviews identify breaks in command, control, coordination, and communication as the major "opportunities to improve" these MASCAL plans.

Response

During the Event

Successful trauma response hinges on effective communication and use of available resources. Employ elements of your MASCAL plan with every injured patient to exercise procedures and to develop "muscle memory" for bigger events. Since the formal MASCAL plan is initiated only when the top medical official decides that resources cannot keep up with medical demands, many units never need to launch the full plan. But the overload may be hard to recognize if a "slow burn" continuous stream of casualties, no one by itself too much for the facility, steadily depletes resources (a particular risk for Level 1 and 2 units). Sudden "flood" MASCALs are usually easily recognized, even before the wounded arrive at the facility.

If advance warning is received, preposition personnel in accordance with your MASCAL plan and anticipated needs. Notify all on-duty personnel and make sure



Mark sides with colors and make large enough for several litters on each side, patients' heads to center.
Triage by classic ABC's, 10-15 seconds per casualty. 1st sweep: assess/treat two A's: *Arterial Hemorrhage an Airway.*
2nd sweep *Breathing* and *Circulation* and document injuries, vital signs, treatments and times on casualty card or trauma form.
3rd sweep, *Disability* with rapid neurological exam and GCS and *Exposure* to look for missed injuries and portect from hypothermia.
Identify patients for surgery and transport at any point. Treat shock with IV and careful hypotensive resuscitation, titrating fluid to mentation to keep systolic BP ~ 60 mmHg to prevent end organ damage while reducing blood loss from a higher circulatory pressure.

Fig. 2.3 Triage triangle system used for field triage of multiple casualties and prioritization for evacuation

you have reliable methods in place (pagers, runners, public address system) to activate a full recall of all key off-duty personnel. Close proximity of living areas for personnel can minimize notification and response times. MASCALs rarely happen when your hospital is empty, so you must incorporate a plan for expanding bed capacity as well as relocation or discharge of current inpatients. Security forces can be deployed and the manpower pool can be mobilized in advance to be ready as runners, litter bearers, blood donors, and other non-provider responders.

While any unit can quickly find itself in a "casualty scene" response, such as when local blast casualties flood its gates, Level 1 units may be more frequently called to initiate hasty on-scene triage and response near hostile fire. A quick survey of the scene will define security issues, as well as the number and nature of injuries. An effective tool in outdoor response is the *triage triangle* (Fig. 2.3), allowing the triage officer (TO) to move around the center to quickly assess each patient and to direct interventions as needed to "Treat and Transport".

Level 2 and 3 triage is better optimized within the treatment facility with prepositioned personnel and equipment. You will almost never perform the television type of triage (such as seen on the popular series M.A.S.H) where all the casualties arrive at once and you run from patient to patient barking orders. You will most often receive widely spaced waves of casualties of two to eight at a time, corresponding to the evacuation vehicle capacity. Do not expect them to arrive or to be off-loaded from the vehicles in order of acuity, which is why your job of continuous triage and reassessment is so critical. The spacing does allow time for each group to be evaluated and treated, but you must move casualties promptly out of the triage area to be ready for the next arrivals.

Hospital Level Triage and the "Triage Officer"

An effective triage officer (TO) is the key to MASCAL success and should be the unit's most experienced combat trauma provider. A senior surgeon is ideal, if other surgical personnel are available to man the operating room, but the TO should not be the sole surgeon. The TO commands the trauma triage scene, but will require other coordinators to attend to elements such as communications, security, and transportation. The TO role demands rapid assessment and decision making: "right, wrong, but never uncertain!" The only wrong decision is indecision, and arterial bleeding and airway are trump cards as patients are sorted into classic NATO immediate, delayed, minimal, and expectant categories (Fig. 2.4). The TO sorts casualties, identifies immediate life threats, and directs other team members to implement critical interventions such as tourniquets, airway management, vascular access, or thoracostomies.

The TO should be located in a position that allows access to all incoming casualties and easy communication with the other key personnel and MASCAL leaders. This is often best achieved by creating a one way "funnel" for patient movement into the facility, with the TO positioned at the narrow point that only allows for one or two patients at a time. This position should be located at or near a centrally-located Casualty Tracking Board. The tracking board assures visibility for all casualties, serving as a hub for triage, treatment, nursing, and patient

Triage and Evacuation Categories

- Standard NATO nomenclature is recommended, often called "DIME"
  - (yellow) – **Delayed** (yellow tag) – may be life-threatening, but intervention may be delayed for several hours with frequent reassessment – (fractures, tourniquet-controlled bleeding, head or maxillofacial injuries, burns)
  - (red) – **Immediate** (red tag) – immediate attention required to prevent death – usually "AABC" issue – airway, arterial bleed, ventilation, circulatory
  - (green) – **Minimal** (green tag) – ambulatory, minor injuries such as lacerations, minor burns or musculoskeletal injuries – can wait for definitive attention
  - (black) – **Expectant** (black tag) – survival unlikely, such as extensive burns, severe head injuries
- Triage categories differ from Medical Evacuation categories :
  - (red) – **Urgent –** save life or limb, evacuate within 2 hours
  - (red) – **Urgent surgical –** same but must go to higher Level surgical capability
  - (yellow) – **Priority –** evacuate within 4 hours, or may deteriorate into urgent
  - (green) – **Routine –** evacuate within 24 hours to continue medical treatment
  - (green) – **Convenience –** administrative movement

Fig. 2.4 Color coded scheme for DIME system of triage classification (*top*) and separate scheme used for medical evacuation (MEDEVAC) chain administrative personnel to update critical information and coordinate care. The TO job does not end at the initial triage, but includes continuous triage and prioritization of patients for movement to the CT scanner, operating room, ICU, and wards. We found that having the TO, the chief Emergency Department Nurse, the hospital bed manager, and the senior Anesthesia provider all located in this spot allowed for improved communication to prioritize and facilitate patient triage, bed assignments, and movement from the ER to the OR or wards.

The TO performs rapid but focused individual patient assessments, usually spending about 15 s per casualty with each sweep. The sick are sorted to receive appropriate treatment, the minimally wounded are moved out of the stream, and the dead or hopelessly injured are sent to the expectant area or morgue. The TO then re-triages the casualties, rapidly checking for any change in status, adding detail to the exam and looking for additional injuries. There will always be mis-triage! The key is to have a system in place to identify them early, notify the TO, and re-triage them appropriately.

Figure 2.5 outlines the setup and triage operation used at the Baghdad Level 3 hospital. In this model, the senior surgeon conducts hasty triage of casualties as they enter the emergency reception area, quickly assessing consciousness, mechanism of injury, scope of apparent wounds. The most severe immediate surgical patients are sent to one of three intensive resuscitation bays, less seriously injured patients sent to

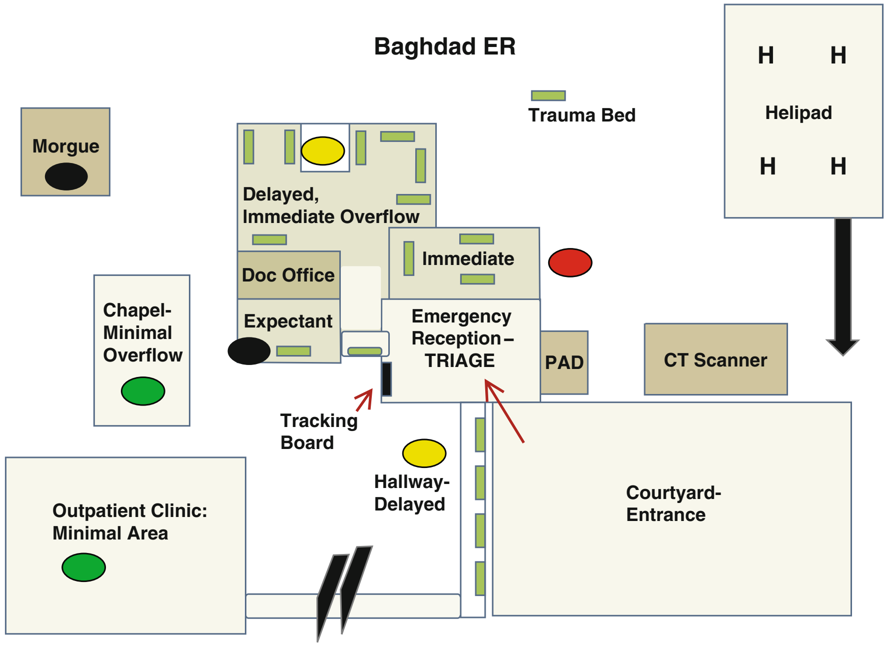


Fig. 2.5 Physical layout and organization used for triage at the Level 3 Combat Support Hospital in Baghdad, Iraq during Operation Iraqi Freedom

a seven-bed delayed area with similar intensive resuscitation capability. Other delayed and non-ambulatory patients are assigned litters in the hallway away from the emergency room. Minimal patients can be led to the outpatient clinic for evaluation and treatment. Don't forget to use your primary care and outpatient assets – they are invaluable for managing these lesser injured patients. Patient Administration personnel positioned at the entrance simultaneously place a trauma packet with each patient, while the nursing coordinator records the trauma number and nature of injury by the assigned bed number on a Casualty Tracking Board. Medics immediately fasten the trauma number bracelets on casualties upon arrival to the assigned litter. Patient flow should ideally be linear, one way in, one way out with security to control access to the triage and treatment areas. Disarm all casualties and confirm "safe" status in trauma bed. Have patient administration personnel maintain accountability for military equipment and weapons. Secure personal effects, to include any amputated body parts, and label clearly with patients' trauma numbers.

Identification of patients is critical, and many systems exist (SSN, trauma registry numbers, and others.). Keep in mind that no system is infallible, and great care must be taken to avoid confusion as to patient identity. For example, confusion among three severely injured casualties with adjacent numbers and similar devastating injuries resulted in a mismatched blood transfusion, and a more random assignment of numbers was adopted to make distinctions among patients more apparent. The importance of careful confirmation of trauma registration number with identity bracelet prior to interventions such as blood transfusions cannot be overemphasized.

The Level 2 or 3 TO is also responsible for prioritizing patients for operative intervention. These decisions can be tough if casualties arrive in wave fashion, as someone with more urgent injuries may arrive in the next group. Once operating tables are filled, additional urgent surgical patients must be managed through temporizing measures with techniques from ATLS and Tactical Combat Casualty Care until the operating room is available. The TO should assign personnel to specific trauma treatment beds, with orders to fully evaluate and stabilize their assigned patient before moving on to a different task. Avoid the "butterfly effect" where providers flit from bed-to-bed without taking responsibility to direct medical care or document findings, resulting in worthless duplication of assessment and delays in appropriate treatment.

Some of the incoming patients may have received various pre-hospital treatments, or even surgical intervention at a Level 2 or local civilian hospital. Often they arrive with little to no documentation of what has been done to them. However, even if they arrive with complete records they should be evaluated and triaged as if they were newly injured. Transport and evacuation time between facilities can result in dislodged lines, occluded airways, recurrent shock, or the presentation of missed or inappropriately managed injuries.

Rules of engagement during a multiple trauma or MASCAL event dictate life and limb-saving interventions only. The ATLS ABC's are very good, with control of major arterial bleeding as the first priority. Victims of penetrating trauma often do not need cervical spine stabilization, but blast and vehicle-injured patients usually do. The FAST (Focused Assessment with Sonography in Trauma) exam can be a helpful adjunct to rapidly identify surgical candidates with intra-abdominal hemorrhage, but it is operator-dependent and may not be definitive. Only chest and pelvis films are permitted during the triage and treatment phase; other films can be done later. Be sure to keep films with the patients, as they are easily lost as patients move through the trauma chain. Many trauma patients will need the CT scanner, as its use has facilitated more accurate trauma diagnosis and management, but few need it for immediate triage. CT candidates must be stable and resuscitated before going into the scanner. An on-site radiologist can expedite scanner throughput.

Military physicians are tasked to provide the same role of care in the deployed setting as in the US. In the urgent resuscitation Level 1 environment, providers may be pushed to render life-saving care outside their specialty training, but most Level 2 and 3 units are staffed with sufficient expertise. A MASCAL is not the setting to learn new techniques, and a capable provider should be engaged as soon as possible, particularly if a provider encounters difficulty in performing a treatment or procedure. For example, if a primary care or emergency provider has trouble with securing an airway, an anesthesia provider should be promptly summoned. Responsibilities and authority need to be defined in advance: an emergency physician should usually defer to the operating surgeon in triage and care decisions. When personnel step out of assigned roles, they can degrade the unit's performance.

Documentation of care is critical. Assign a recorder to each trauma table who can accurately complete the casualty card or trauma sheet. If documentation is left until after the event, fatigue and degraded recall may make accurate reconstruction impossible. In Baghdad, we found that despite our most diligent efforts, urgent surgical patients were rushed to the operating room without supporting documentation (another factor in the blood transfusion mismatch). We developed a simple bright yellow cover sheet that had the pseudo-SSN, and key studies, meds, blood products, and diagnosis. This sheet always remained with the patient, even if more detailed trauma sheets needed to follow later.

In addition to the TO, an overall scene or incident commander or coordinator can maintain "big picture" focus to call for specific additional assistance and to maintain movement of patients out of the emergency treatment area in order to prepare for the next wave of casualties. Hemodynamically stable delayed patients can be admitted to a holding bed or ward to complete studies and treatment or surgery when OR and CT demands have slowed. Non-surgical medical providers can care for delayed and minimal casualties away from the emergency area to decompress scene. A surgeon should sweep these areas to prioritize delayed patients in the operative queue and to reassess clinical status.

High visibility events may trigger immediate inquiry from higher headquarters or government officials, especially if "high value" or visibility victims are involved. Frequent updates of senior officials and commanders may be required; build current contact lists of "need to know" officials before an event.

Special Considerations: Mental, Behavioral Health and Spiritual Needs

The wounded certainly benefit from ministry team comfort and encouragement, but unit and family members who accompany injured patients also have anxiety and grief burdens to be addressed while awaiting news about loved ones' status. A chaplain can be an invaluable advocate and assistant to calm units and families and to keep them updated, but other personnel may also meet many of these needs with attentive compassion. Remember that members of a unit who bring their wounded buddies for care may be unaware of their own injuries due to the "adrenaline of battle". Have a low threshold to register them with trauma numbers and to appropriately assess them as casualties.

Psychiatric casualties present a difficult management challenge, particularly during a MASCAL scenario. Although not physically injured they can significantly disrupt your team function and monopolize the time of key personnel that are needed elsewhere. You should be fully prepared for this; integrate a disruptive psychiatric casualty into your MASCAL practice exercises (your team will quickly realize how incredibly difficult they can be to manage) and have a designated mental health professional or team as part of your standard MASCAL response.

One of the hardest missions may be to care for your own injured personnel. While focus may be sustained during emergency evaluation and treatment, special attention for your personnel will be essential during the "reset" phase when the full weight of the strain and loss is experienced. Common responses you may encounter among your personnel are inappropriate or disproportionate outbursts of anger, major sleep disturbances with resultant fatigue, and major depressive symptoms. Do not ignore these warning signs or just hope that they will go away.

Route

Transport and accountability must be inextricably interwoven. Dedicated transport personnel should meticulously record every patient's movement from the triage and treatment areas, noting the destination on a Tracking Board or log. It is very easy to lose control in the confusion of large events. In Baghdad, following the bombing of a high official's home, a final tally of casualties and dispositions took more than 2 days due to inaccurate record keeping. Any movement of military or contract personnel must include notification of unit commander or supervisor.

A patient transfer decision considers diagnosis, condition, Level of care required, and expected prognosis and recovery. Most Coalition combat wounds will require evacuation to a Level 3 facility, with subsequent transport to a Level 4 or 5 for follow on care and rehabilitation. Once patients reach a Level 4 facility, they are unlikely to return to theater. There is a big difference between "snatch and grab" point of injury evacuation to Level 2 or 3 facilities, and inter-facility transport of critically ill or injured patients. Movement of these patients from one higher Level facility to another requires special planning and coordination, as many will require complex monitoring and care en route. If possible, avoid evacuating an unstable patient because military helicopters and tactical vehicles are poor resuscitation platforms (see Chap. 34). Adequate space must be assured for critical care attendant to be able to access monitors and lines.

Reset

Triage stops when the last patient has been moved from the emergency triage and treatment area. Once transport has been finalized and patient documentation completed, the care team should begin to recover and to prepare for the next event. Recap the event and confirm accountability for all casualties. Call in the report to higher headquarters. Lead an after action review to find points to praise as well as problem areas to improve to make the next response more effective. Do not neglect personal and patient safety concerns. The treatment area may need to be cleaned, and supplies must be rapidly restocked. Remember that "amateurs talk strategy while experts talk logistics" – if you run out of critical supplies and equipment you are mission incapable.

Ethics and Resiliency

Triage by its nature raises issues of distributive justice and beneficence. Combat triage may confront teams with challenges in deciding between care for a suspected or known enemy combatant and a US Soldier. Expectant patients, particularly with burns and catastrophic head injuries exact a huge toll on treatment teams and the victims' units and families. In OIF, severe burns of non-coalition personnel of more than 50% total body surface area were generally non-survivable, without Level 4 or 5 burn center support. A refusal to initiate care can be very tough. An ad hoc ethics committee process can be invaluable to help ratify these and other difficult decisions.

If possible, expectant and morgue areas should be in a covered location away from the rest of the patients. Position a nurse or medic to give any needed pain medications or fluids, and utilize the ministry team or other capable personnel to ease anxiety and fear and to provide comfort. Preserve dignity and treat with the same respect as other patients. Reassess after other casualties have been triaged, as clinical status may have changed and post-event unit capability may enable more intense attention and care.

Multiple trauma events are stressful, and care for the responding team members is essential. Sleep rest cycles and meals cannot be neglected. Compassion and awareness are integral to the team refit and recovery process to address emotional needs in the wake of the horrors of devastating or fatal injuries. Unit ministry and behavioral health team attention may be as important to your team as medical resupply. Notify your higher headquarters if your facility is "black" due to staff or supply exhaustion or other constraints that temporarily prevent quality patient care.

Conclusion

Trauma triage and response are among the most important missions of US medical forces. While each unit will have unique perspectives and experiences, all will benefit from careful consideration of resources, rehearsal, response, routing of casualties, and reset. We have described a system of flexible response that can be scaled to one casualty or to dozens. Recognize the cost of trauma care, and assure rapid refit of your units' capabilities, heart, and soul. You will know the victory and thrill of a job well-done, and you will be ready to do it again.

Chapter 3
Initial Management Priorities: Beyond ABCDE

Alec Beekley

Deployment Experience:

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BLUF Box (Bottom Line Up Front)

1. Prepare for combat trauma surgery by reading, review of case scenarios, and visualization.
2. Focus on one patient at a time. During multiple casualty events, stay with the casualty to whom you are assigned.
3. In combat trauma C comes before A and B. Assess for and control hemorrhage immediately, it is what will kill most of your patients.
4. Assessment of airway (A) should be rapid in combat casualties; it is generally an "all or nothing" phenomenon. Intubation can often wait until you get to the OR.
5. B is for tension pneumothorax, auscultate and augment with ultrasound or CXR.
6. Check tourniquets for adequacy and tighten or augment with pneumatic tourniquets, particularly for proximal amputations.
7. Perform a FAST exam early. Obvious abdominal injury in unstable patients should prompt abandonment of the FAST and rapid movement to the OR.
8. Portable chest and pelvis x-rays can be taken in the trauma bay and brought to the OR – they may provide valuable data.
9. Get help in the OR, particularly for multi-system combat casualties. Do your damage control procedures in tandem, not in series.
10. Intra-operative findings should match patient physiology – if they don't, you need to conclude the operation you are doing and look for the real hemorrhage sources.

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> *How varied was our experience of the battlefield and how fertile the blood of warriors in rearing good surgeons.*
>
> Thomas Clifford Allbutt

Multiple casualties have arrived. You can hear more Blackhawks landing on the helipad outside. The first casualty has rolled into the next trauma bed after being assigned to your colleague by the triage officer. You notice exposed brain bulging from a jagged hole in the frontal bone. Omentum hangs from wound on his left flank. The left lower extremity is missing from about mid-thigh – two tourniquets are in place side by side. The area around the litter is a bustle of activity.

The next casualty is brought into you. You have an initial wave of anxiety. You haven't been here long. Aside from an obvious open tibia/fibula fracture in his right leg, he is talking, telling you he is okay and to help his buddies first. Your cursory primary survey appears negative – airway intact, breath sounds clear, and palpable radial pulse. You begin to drift over to the first casualty. He is clearly going to need a lot of operations and your colleague is hard at work…

The scenario just described can happen any day at any surgical unit in Afghanistan, Iraq, or any other modern conflict. You may find yourself as the only surgeon or only one of two surgeons available to handle multiple severely injured casualties at once. Hence, any discussion on "initial management priorities" must take into account that these priorities may change based on the ratio of severely injured casualties to surgeons. One day, a casualty with a brain injury may get full resuscitative efforts; the next day, the same casualty may be made expectant due to the nature of the other casualties and the resources available. Triage and initial management priorities are not set in stone, but are dynamic processes that always take the local conditions and capabilities into account.

The process is triage, a simple sorting and prioritization that occurs with multiple casualties. This topic will be discussed further in another chapter. The process by which the surgeon approaches the individual multiply-injured combat casualty, however, should also be thought of as a sorting and prioritization exercise. Every move you make, particularly in the first few minutes of the trauma evaluation, should be prioritized toward identifying life threatening injuries and bleeding, followed by likely injuries that require immediate intervention, and lastly a detailed survey to identify occult or lower priority injuries. Even if the patient is "stable," proceed like he could become rapidly unstable in the next minute. You don't want to be shooting a femur x-ray when the patient becomes unstable and you realize you haven't done a FAST exam or a chest x-ray yet. Like all operations surgeons perform, this exercise can be simplified by breaking it down into a series of steps.

The first step, and perhaps the most important one, is FOCUS on your patient. One of my most senior surgeon mentors and friends used to say that the surgeon must develop the ability to block out distractions, both internal and external. The surgeon's pounding heart, sweaty hands, and self-doubt are internal distractions. Each surgeon must figure out on his own how best to minimize and overcome the stress of caring for severely injured brothers and sisters in arms. Some surgeons do not suffer much from doubts ("often wrong, never in doubt"), but many of us do (if we are honest with ourselves). Some surgeons choose to mentally prepare by reading textbooks; others, by presenting hypothetical surgical challenges and figuring out what to do with them. Choose a method and PREPARE ahead of time. Regardless of your background, prior deployments (or lack thereof), and civilian trauma experience (or lack thereof), you WILL be challenged by combat casualties. Mental preparation, study, and visualization can lessen the stress the first time. And ALWAYS ask for help when needed – trauma is a team sport in the combat or disaster setting.

The casualty with exposed brain, evisceration, and a missing limb on the next litter is an external distraction. External distractions must be minimized in order for you to serve your patient best. The key point for surgeons new to the combat environment to learn is to STAY WITH YOUR PATIENT, particularly during multiple casualty events (which happen frequently). Focus on one patient at a time. The surgeon in the scenario at the beginning of the chapter is at risk for drifting away from his assigned casualty and missing important findings. If you are needed elsewhere, the triage officer will re-assign you if your patient is truly stable. In the meantime, attend to your patient until you are confident that your workup is complete or you have appropriately handed the casualty off to another provider.

Initial Management Priorities

Sick or Not Sick?

When the surgeon approaches a combat casualty for his initial evaluation, his first determination should be binary: is this patient sick or not sick? In other words, is this patient at risk for dying? This should always be the surgeon's first assessment, regardless if the patient was triaged into a delayed or minimal status. This determination can be the one that leads the surgeon down the path to success – or to failure if this determination is wrong. Simple techniques are right most of the time. They require hands-on engagement with the patient. Talk to him: "How are you doing, bud? What happened to you? Can you hold up 2 fingers?" While you are asking these questions, feel for the casualty's radial pulse. A casualty that answers you, can hold up two fingers (GCS motor score of 6), and has an easily palpable radial pulse is usually not too sick.

Casualties that are initially deemed "not sick" can usually have a relatively thorough and detailed assessment, including CT scans and plain films for suspected injuries. Casualties that fail any of these initial assessments should immediately raise your level of concern and focus. They should be considered unstable and seriously injured until proven otherwise. Patients who fall into this category (unstable or "sick") should prompt the surgeon to perform a rapid search to find the source of their illness and think about moving them expeditiously to the OR.

Hemorrhage Control Über Alles

Although the A of the Advanced Trauma Life Support ABCDE algorithm stands for “airway,” in the combat casualty the airway is rarely the source of threat to life. This is particularly true if they have survived the evacuation process to reach you with an intact airway. When there is a significant airway issue, it is usually quite obvious and will be apparent that this has to be dealt with first. The biggest threat to a combat casualty’s life is usually from hemorrhage, so in combat trauma the C should come first. Hence, the initial evaluation in the unstable casualty, while still involving a primary survey, must rapidly move to finding and treating the hemorrhage sources. These include external hemorrhage sources and intra-cavitary hemorrhage; into the chest, into the abdomen, and into the pelvis. In the end, these sources can all be found fairly quickly, usually in a matter of minutes with a focused physical exam augmented with basic and rapid imaging or interventions as needed. Figure 3.1 outlines the basic initial management algorithm and targeted priorities in the combat casualty.

One advantage of combat trauma is 95% of the mechanisms are penetrating. Casualties have holes in them. Their injuries are frequently obvious and often dramatic. Hence, unstable casualties with limbs missing, blood draining, abdominal evisceration, or large holes in the chest should pretty much go to one place – the OR. These obvious injuries should prompt the surgeon to establish intravenous lines, begin resuscitation, and activate the OR, but should not keep him from fully evaluating the casualty. Combat casualties may also suffer blunt or blast mechanisms (which may not create holes in the body), or they may have holes from head to toe. So, after a RAPID primary survey, at a minimum these casualties should have: (1) inspection of the entire body surface; (2) inspection of tourniquets for adequacy/tightness vs. application of tourniquets for suspected extremity hemorrhage sites; (3) FAST exam; (4) a portable chest x-ray; (5) a portable pelvis x-ray; (6) quick scan and hands-on palpation for extremity injuries/long bone fractures; and (7) establishment of large-bore intravenous or intra-osseous access.

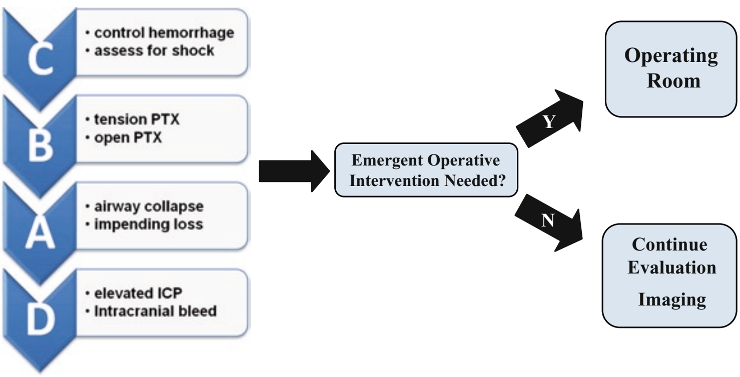

Fig. 3.1 Algorithm for initial management and prioritization in combat trauma

All of these diagnostic tests and maneuvers can be performed at the patient's bedside. The utility of each is discussed below.

1. Inspection of the entire body surface: casualties must be exposed and their body surfaces examined. The critical part of this is the log-roll. This step is easily overlooked, which can have grave consequences for the patient. A casualty may present with a normal looking anterior and have a devastated posterior, the extent of which is only known once he is rolled. These wounds are seen with increasing frequency due to explosions going off under vehicles or behind foot patrols. Profoundly hypotensive patients may have stopped bleeding from posterior wounds, which can then re-bleed under the surgical drapes once the patient gets some resuscitation. Knowledge of these posterior wounds can be critical for the operating surgeon. For example, findings on abdominal exploration that are not compatible with the casualty's level of shock should prompt the surgeon to re-examine the posterior wounds.
2. Tourniquets may have been applied after the patient had already become hypotensive. Less force than normal may have been required to stop hemorrhage, or if the hemorrhage had stopped spontaneously the medic would have no cues to tell him how tight to make the tourniquet. Resuscitation may precipitate re-bleeding, so all tourniquets should be checked and consideration given to supplementing them with pneumatic tourniquets. Assurance of tourniquet adequacy should be done early – it will allow you to focus on finding and treating other noncompressible sources of hemorrhage.
3. FAST exam: This study can also be done almost immediately on casualty arrival and allows assessment of the abdominal, pericardial, and with proper training, the thoracic cavity. Usually, the FAST can be done directly after a quick evaluation of the airway and auscultation of the chest. Unstable casualties with positive findings on FAST exam need rapid transfer to the OR. For equivocal FAST images, a diagnostic peritoneal aspiration (DPA) with a 20-gauge needle can be performed in unstable patients if the source of hemorrhage is not yet clear. DPA can help rule out major hemorrhage into the abdomen.
4. Portable chest x-ray: This study can be done within minutes of arrival and the film brought to bedside directly after development. With auscultation of the chest cavity, life-threat from either tension pneumothorax or massive hemothorax is easily ruled out. Add the evaluation of the chest by portable chest x-ray and potentially life-threatening problems like simple pneumothorax and hemothorax are identified. If your unstable patient has a clear chest x-ray – they are NOT dying from intra-thoracic hemorrhage. Look elsewhere.
5. Portable pelvic x-ray: The portable pelvis film can usually be taken at the same time as the portable chest x-ray, but is of lower priority. It can provide valuable data about the status of the bony pelvis and sometimes about the location of projectiles. Performance of these films can occur without significantly interrupting other assessments and therapies, such as FAST exam and placement of central lines. However, pelvic fractures severe enough to cause instability from hemorrhage are usually obvious on physical exam and you do not need to wait for your x-ray to begin intervention.

6. The extremities can be assessed quickly for long bone deformities. The only location in the extremities for substantial hidden blood loss is in the thighs. Obvious amputations, mangled extremities, active bleeding extremities, and expanding hematomas should prompt direct pressure and/or tourniquet placement if not already done.
7. Establishment of large bore intravenous access: Two large (14–16 gauge) antecubital lines will suffice to start. Usually, surgeons can rapidly place an internal jugular, subclavian, or femoral line 8.5 French short introducer catheter for rapid infusion of fluids and products. Emergency release blood products (PRBC and thawed plasma) should be given in favor of crystalloid to unstable patients with obvious injuries. Remember that unlike civilian trauma, you are often dealing with patients with three or even four severely injured limbs. Do not waste time trying to establish a peripheral IV in these cases and get a reliable large bore central venous catheter in place as soon as possible.

Tension Pneumothorax

Unfortunately, soldiers are still dying in the field or in the Emergency Department from untreated tension pneumothorax. It is critical that surgeons rule out this entity early in the work-up of the combat casualty. There is little downside to empiric placement of bilateral decompression needle thoracenteses or chest tubes in the dying patient. Surgeons must also remember to assess, by auscultation, the chest cavity. Remember, most of the wounds are from penetrating mechanisms, so there will often be holes in the chest – but casualties can get in motor vehicle crashes or falls after the initial penetrating mechanism, or suffer primary blast injury and barotrauma. Learn how to do the rapid ultrasound scan for pneumothorax (see Chap. 6) – it is reliable and faster than x-ray.

Open Pneumothorax

Open pneumothorax or the "sucking chest wound" can easily frustrate surgeons on their first deployment. It is, quite simply, seldom seen in civilian trauma. It is usually not much of a diagnostic challenge. There will be a big hole in the chest with audible air movement and/or gurgling from the wound. Patients can present in a well-compensated state, in which case their problem is primary to irrigate the wounds and figure out how to established surgical chest wall coverage or reconstruction. Keep in mind that patients with open pneumothorax usually had something big tumble through their chest cavity, and massive intra-thoracic injuries may make these patients present in extremis. Patients can also present with impending asphyxia from the open pneumothorax physiology. Simply occluding the hole may not rescue these patients – they usually require establishment of an airway and positive pressure ventilation, as well as immediate chest tube placement. This topic is covered in more detail in Chap. 16.

Airway

Relative adherence to the ATLS algorithm is certainly not discouraged. As a framework for evaluating trauma patients, it is validated and thorough. The reality of combat, however, dictates that casualties who lose airways from gunshot wounds or fragments from explosions rarely make it to surgical care alive. Many casualties with head injuries will get endotracheal intubation or cricothyroidotomy in the field and will arrive to the surgeon with an airway in place. Casualties that do arrive with impending airway loss from a penetrating neck injury are usually quite dramatic and it becomes rapidly obvious that airway control needs to be attained.

Hence, for the vast majority of combat casualties, the airway is an all or nothing phenomenon. The casualties with “nothing” are usually beyond help by the time they reach the hospital; casualties with impending airway loss are usually quite obvious, and either endotracheal intubation or cricothyroidotomy can be rapidly performed; and casualties with an intact airway do not need any emergent airway intervention. In fact, rapid sequence intubation in the unstable combat casualty who otherwise has an intact airway may precipitate loss of abdominal muscle tone, loss of tamponade effects on abdominal hemorrhage, and cardiovascular collapse. The urge to intubate patients for no other reason than they are going to the OR soon anyway should be resisted. Give them muscle relaxants and vasodilatory drugs in a location where you can operate rapidly if need be. Avoid turning a non-issue into a life-threatening distraction from the casualty’s real problem.

So, that begs the question: who *should* have airway control established? There are a few special situations that should be discussed. The first is the patient who sustained severe mandible or maxillo-facial trauma. These casualties, when awake, may present in seated or leaning positions and may be maintaining their own airway by allowing injured tissues to be pulled away from the airway by gravity. For the short term, let them. Attempts to sedate them or lay them supine may be met with aspiration of blood and/or rapid loss of the airway. These casualties can usually have an awake, well-controlled naso-tracheal intubation or a surgical airway done under local. Worst case scenario, you have all the instrumentation and support you need to perform a rapid surgical airway if endotracheal intubation cannot be gained.

The second special situation to get early airway control is the casualty with suspected inhalation injury. Incendiary and chlorine-containing bombs have been used in the current wars, and casualties can be trapped in burning vehicles or buildings. These casualties may have facial burns, singed facial hair, soot in their throat and nares, and an unexplained tachycardia. They may have rapid deterioration over the first 12 h after injury due to airway swelling and edema or lung injury. Based on the patient history and these physical findings, surgeons should have a low threshold to electively intubate these casualties and perform an immediate bronchoscopic examination to assess the presence and degree of injury to the trachea and distal airways. This will greatly assist in determining treatment as well as the timing of future extubation.

Finally, the head-injured patient with deteriorating mental status or presenting GCS <10, and patients with direct but non-obstructing penetrating airway injury should be considered for establishment of early airway control, as they are at risk of suddenly airway loss or aspiration, as well as hypoxic episodes which should be avoided at all costs in the head injured casualty. Secure the airway as soon as possible, but again the principle applies that if they need to go immediately to the OR and their current airway is intact, put them on oxygen and secure the airway in the OR.

A final note on airway management: You will benefit more patients by becoming adept at performing adequate bag-valve mask (BVM) ventilation then you will by performing emergent surgical airways. This maneuver is woefully under-utilized in the initial trauma setting, and you will often observe the assigned "airway" personnel focused on preparing intubation drugs and equipment while no one is performing simple BVM ventilation. You should be able to indefinitely temporize most inadequate airway and breathing situations with good BVM technique, turning a panicked emergency procedure into a calm and controlled maneuver. The only real exception to this is the true mechanical airway obstruction, usually due to foreign body or severe facial fractures. The key technical aspect is to always lift the patients face into the mask rather than push the mask into the face. Hook your fingers under the mandible of the jaw and lift anteriorly, sealing the mask around the mouth and nose. This is preferably done with both hands (two person BVM), and then deliver adequate breaths with high flow oxygen. You should immediately see improved oxygen saturation and auscultate adequate breath sounds.

Massive Extremity Injuries

No matter what your specialty, the most common scenario you will encounter in combat trauma is the patient with a severely injured, mangled, or amputated extremity. You will usually not have an Orthopedist immediately available during your initial evaluation, so you must understand the basics of the early evaluation and management. Unlike most civilian trauma, the injured extremity is often the source of life-threatening hemorrhage in these patients and should be immediately controlled as described above. It is also usually obvious that these wound will require emergent management in the operating room, and there is very little that you absolutely have to do with them in the Emergency Department. Perform a basic assessment of the sensation and motor function of the extremity. Vascular status should also be assessed but may be compromised if there is a proximal tourniquet. Do not take the tourniquet down unless you are immediately prepared and able to re-establish complete proximal control. If you have time, obtain an AP and lateral x-ray which will help delineate bony injury as well as identify the presence and degree of foreign body contamination. **Do not delay movement to the OR for**

extensive extremity x-rays; most of these injuries do not require an x-ray for the initial operative management or they can be assessed with C-arm in the operating room. Irrigate the wounds with betadine, wrap them, and splint the extremity to help minimize additional motion injury and pain. Administer antibiotics as soon as possible with both gram positive and gram negative coverage.

Unexploded Ordinance

Your next patient arrives, another extremity wound with a big piece of metal embedded in the soft tissue. **No big deal – until you realize that it is actually an unexploded rocket propelled grenade** (Fig. 3.2). It doesn't matter how good your residency or fellowship training was, this will be something you have not seen before or been prepared for. Check your pulse, take a deep breath, and then take care of your patient. Your efforts know should focus on (1) protect yourself and your unit, (2) avoid inadvertent detonation, and (3) remove and dispose. Immediately isolate this casualty, preferably by moving other patients out of the area. Notify your local explosives and ordinance personnel who may be invaluable in providing assistance and expertise about this particular explosive. If this occurs in a MASCAL situation, then this patient should be moved down on the priority list until you have taken care of the other urgent patients. You can safely x-ray the involved area if necessary, **but do not use ultrasound!** Turn off any cell phones or similar devices in the immediate area. Now prepare your team and OR for removal.

Minimize the personnel involved in the procedure to only those absolutely necessary. All should be wearing full body armor and ballistic goggles. Create a hasty protective barrier (sandbags) around the patient, at least up to waist height.

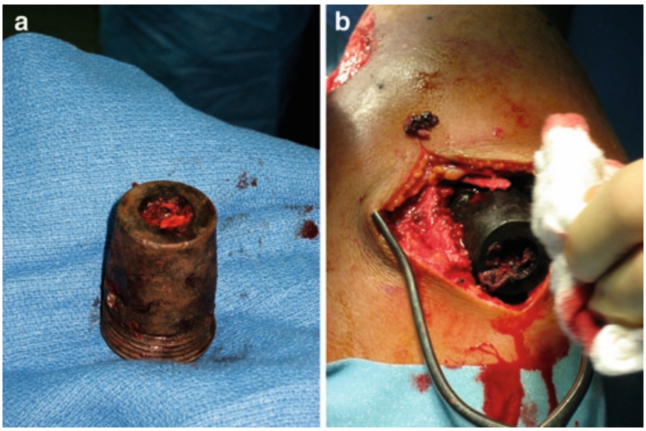

Fig. 3.2 Unexploded rocket propelled grenade (**a**) removed from a soft tissue wound (**b**) by a surgeon with a Forward Surgical Team in Afghanistan

Ensure full chemical paralysis before starting. Do not use any electrocautery devices, and never use a defibrillator until the device is removed. Manual retraction and manipulation should be used as much as possible to avoid touching the device with any metallic instruments. A self-retaining retractor may be used if necessary but avoid any contact with the explosive. Gently encircle the device and remove it from the wound, handing it off to the ordinance personnel for disposal. Now you can control bleeding and proceed as with any other patient.

Operating Room Priorities

Obviously, a complete discussion of what may be necessary in the OR would extend far beyond the confines of this chapter and this book. Nevertheless, several simple strategies can help you prioritize the hemorrhage sources in the multi-system casualty.

1. Get help. Get another surgeon or six more. Get as many as you need to have one or even two surgeons addressing each hemorrhage source. We would routinely have two surgeons working on the abdomen, two surgeons on each lower extremity, and a surgeon working on a casualty's face. Combat trauma surgery is a team sport. The old adage, "You can call for help, but it's a sign of weakness," should be thrown out and replaced with "If you don't call for help, you are doing your patient a disservice."
2. On occasion, multiple extra surgeons won't be available. Have a methodical plan to address each hemorrhage source. Tourniquets can usually keep extremity hemorrhage controlled while you look elsewhere. The abdomen is often the best place to start if signs point to an injury there. Exploration can rapidly tell you if the abdomen is the source of instability. If the abdomen is not full of blood and there is not a massive hematoma in the pelvis, time-consuming exploration of every small, non-expanding retroperitoneal hematoma or even control of bowel contamination can be delayed for several minutes while you look elsewhere for the source of hemorrhage in the unstable patient. Prep and drape all significant injuries, including extremities, into the surgical field. This will avoid the "bleeding under the drapes" phenomenon which has fooled many surgeons before you.
3. Patients that have had chest tubes placed have a readily available way to see if they have ongoing bleeding in the chest. While clotting of chest tubes can occur, it is relatively rare, and if in doubt a second chest tube can be placed. Inspection of the diaphragms during laparotomy can help you identify tension pneumothorax or expanding hemothorax.
4. That leaves two areas – the patient's extremities and posterior wounds. Extremity hemorrhage, unless not controlled with tourniquets or clamps, will usually respond rapidly to resuscitation. The other hidden hemorrhage source in combat casualties is from posterior injuries – gluteal vessels, popliteal vessels, scalp, and posterior holes in the chest that allow drainage of thoracic blood. This fact highlights the importance of the complete inspection of a casualty's body in the

trauma bay. These posterior wounds may be non-bleeding at the time of patient arrival, particularly in patients in shock – as resuscitation commences, these areas may begin to re-bleed. Hence, if minimal intra-abdominal or thoracic findings do not match a patient's deteriorating physiology, the operations should be halted and an additional search for hemorrhage begun (which may involve tearing down sterile drapes and rolling the patient again).

5. Always start with damage control measures as the default – non-definitive control of contamination, temporary closure of the abdomen, shunts in major arterial and venous injuries – and then make the patient prove that you don't need to use damage control measures. Remember, damage control may be necessary not because of the patient's physiology but because other casualties may need the OR table.

The "Blood Vicious Cycle" Revisited

One of the most over-used and poorly understood concepts in trauma is the "bloody vicious cycle" or "the lethal triad" of hemorrhage, acidosis, and coagulopathy. Every medical student can rattle these off as the three priorities to be addressed in trauma, or as the trigger for changing from definitive surgery to a damage control approach. This has become so pervasive that many have forgotten that each element of this triad is a RESULT of some injurious process and not necessarily harmful in and of themselves. In fact, each element of this triad is often used therapeutically in critically injured or ill patients. Hypothermia has multiple beneficial effects on metabolism and physiology, and there is much ongoing research about using hypothermic arrest as an initial intervention to buy time in critically injured trauma patients. Acidosis will improve oxygen delivery and has not been demonstrated to be directly harmful to enzyme or physiologic function until a critical pH is reached (at least 7.2 or lower). Finally, coagulopathy in the trauma patient is actually a complex mix of hyper and hypo-coagulable states, and in many cases decreasing clot formation may be beneficial at the micro and macro vascular levels.

If your patient has any or all elements of this lethal triad, you should focus on addressing the root causes and halting the progression to irreversible shock. Simply attempting to directly correct these three factors will waste time and resources, and may actually worsen the outcome. You can warm your patient all you want – if you haven't controlled bleeding or spillage then it doesn't matter what temperature they die at. In fact, it may actually hasten their death. Push amp after amp of bicarbonate and you may make the pH look better, but you aren't treating the real problem or doing the patient any good. Figure 3.3 shows the elements of the lethal triad as peripheral factors which are driven by several core processes in the trauma patient. Address the core factors, and trend the changes in pH, temperature, and coagulopathy to tell you whether you are winning or losing the battle. Focusing your efforts on addressing these core factors is the only way you will defeat the "bloody vicious cycle."

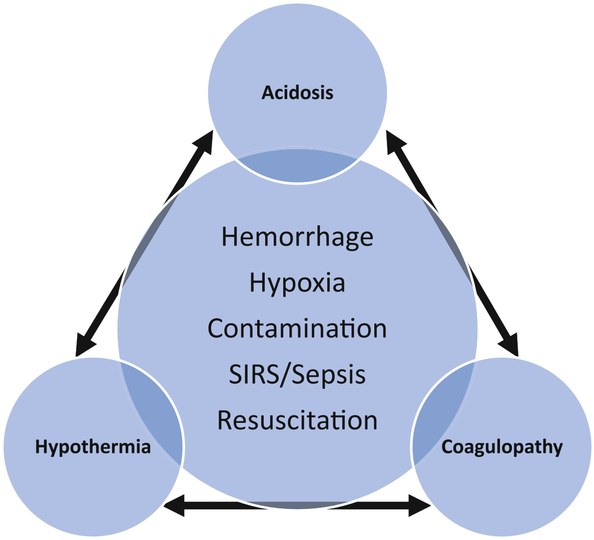

Fig. 3.3 The "lethal triad" revisited. Treatment of the trauma patient should focus on the core causes of acidosis, coagulopathy, and hypothermia shown in the center circle

The Multi-System Combat Casualty: Putting It All Together

You may have noticed that obtaining a CT scan was not listed above in the initial management priorities. The reason for that, quite simply, is that the astute general surgeon can learn what he needs to know about an unstable casualty to make the decision to go to the OR from straight-forward bedside tests. The unstable patient with a head injury is best served by getting the source of his instability treated. That source is usually NOT his head injury. On occasion, this may result in the surgeon taking a patient to the OR for laparotomy only to find that the patient had an unsurvivable brain injury on post-laparotomy CT scan. THIS SHOULD NOT BE CONSIDERED A FAILURE. It was the correct decision based on the data available to the surgeon. A failure would be to take an unstable patient to the CT scanner for head CT scan under the mistaken belief that the patient had an unsurvivable brain injury, only to find that they did not. Surgeons must be prepared to make decisions based on incomplete data. This is triage applied to the individual patient – the sorting and prioritization of injuries to bring maximum resources to bear.

This algorithm of priorities for the surgeon evaluating the multi-system combat trauma patient is summarized below:

1. Focus on the patient in front of you.
2. Determine if they are "sick" or "not sick."
3. If sick: identify and treat sources of hemorrhage.
4. Establish more definitive control of pneumothorax (chest tube).
5. Identify and treat airway problems.

6. In the OR, stick to damage control measures as the default. Make sure operative findings match the patient's physiology – if injuries are minimal but the patient is still sick, you haven't found and treated all the hemorrhage sources yet.
7. Only after all of the above have been treated and the patient deemed stable, elective CT scans and plain x-rays based on physical exam findings may be obtained to rule out non-life threatening injuries.

Chapter 4
Damage Control Resuscitation

John B. Holcomb and Timothy C. Nunez

Deployment Experience:

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BLUF Box (Bottom Line Up Front)

1. Damage Control Resuscitation is intended for the 10% of combat casualties who require a massive transfusion.
2. Damage Control Resuscitation is a continuum that begins in the pre-hospital environment and continues through the casualties arrival to higher levels of care.
3. Assume the combat casualty is coagulopathic and acidotic on admission.
4. Early identification of the casualty who will require massive blood transfusion is critical, the goal is to "stay out of trouble as opposed to getting out of trouble."
5. Permissive hypotension, limited crystalloid resuscitation, and rapid delivery of predefined ratios of component blood therapy or fresh whole blood are the foundation of Damage Control Resuscitation.
6. If recombinant factor VIIa is to be used, it should be administered early and in the dose of 90–120 mcg/kg.
7. In austere locations where banked blood is a scarce resource, early utilization of a walking blood bank may be necessary.
8. Your goal should be a balanced resuscitation and not an arbitrary number or ratio
9. Make it automatic and foolproof! Establish a protocol that delivers all blood products as a "DCR pack" containing packed cells, plasma, and platelets in a 1:1:1 ratio.
10. Over-resuscitation is as great a sin as under-resuscitation in the trauma patient – amateurs can resuscitate, experts know when to stop.

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"The only weapon with which the unconscious patient can immediately retaliate upon the incompetent surgeon is hemorrhage."

William S. Halsted

Introduction

Treatment of active hemorrhage, hemorrhagic shock, and prevention of re-bleeding is the name of your game in combat trauma. There are two big killers on the battlefield: severe brain injury and hemorrhage. You can't do a lot about the former, but through preparation and attention to detail you can significantly impact the latter. Assume every injured patient you receive has active bleeding until proven otherwise. Look at your watch when the patient arrives, and keep that ticking clock in mind during your initial trauma evaluation and resuscitation. The whole philosophy of damage control resuscitation (DCR) can be summarized by the observation that "Patients bleed warm whole blood, not just red cells. Therefore we should replace this with warm whole blood or the equivalent, not cold and coagulopathic packed red blood cells, starting from minute one of the resuscitation."

Hemorrhagic shock and exsanguination are responsible for a large number of deaths in civilian and military trauma, accounting for more than 80% of deaths in the operating room and nearly 70% of deaths in the first 24 h after injury. Fortunately, only approximately 10% of military trauma patient admissions will require a massive transfusion (current accepted definition is ten or more units of packed red blood cells in the first 24 h). This group of patients who require massive transfusion will account for the majority of blood utilization in deployed military treatment facilities (MTF). The recent conflicts in Southwest Asia have been the major stimulus to the rapid development, evaluation and acceptance of Damage Control Resuscitation (DCR). Several authors have demonstrated improved survival by using increased amounts and earlier use of predefined ratios of blood products, early in the care of these severely injured patients, in both military and civilian settings. Rapid processing and preparation of such a large amount of blood and blood products in a short period of time requires significant planning and prior coordination of personnel and dedicated resources to ensure delivery of these products in an immediate and sustained fashion.

Previous descriptions of the coagulopathy from trauma were based on laboratory data from the operating room and the conclusion was that abnormal coagulation laboratory values were not found in the first hours after injury, and were associated with dilution. However, we now know that at least 25% of trauma patients arrive at the trauma center already coagulopathic and that these patients are at a markedly higher risk of mortality. The coagulopathy of trauma is a separate entity characterized by non surgical bleeding that can occur with or without appropriate concentrations of coagulation factors. Therefore, it has become paramount to have strategies in place (DCR) to directly address this coagulopathy in the severely injured patient. I like to always assume that the severely injured casualty is coagulopathic on admission and should be treated accordingly.

Damage Control

The damage control concept has been available as an alternative approach to management of the exsanguinating trauma patient who becomes cold and coagulopathic during laparotomy since the early 1980s. In the 1990s several authors applied the term "damage control" to this surgical resuscitation strategy and delineated damage control into three separate and distinct phases. Phase one consists of the abbreviated laparotomy, with the addressing of life-threatening hemorrhage and gross bowel spillage. The second phase involves the restoration of the patient to "normal" physiology through correction of acidosis, hypothermia, and trauma associated coagulopathy. Phase three involves the return to the operating room for definitive repair and reconstruction of injuries temporized during phase one. Phase three occurs after restoration of "normal" physiology is achieved. Damage Control Resuscitation (DCR) spans all three of these phases.

The concept of DCR evolved out of this same approach. In the patients anticipated to need a special surgical approach, (damage control surgery), we have developed the concept of a special type of resuscitation (damage control resuscitation). DCR is composed of three basic components: (1) permissive hypotension- maintain palpable distal pulses in an awake patient, (2) minimizing crystalloid-based resuscitation strategies (prevention of ongoing hypothermia and dilution) and (3) the immediate release and administration of pre-defined blood products (packed red blood cells, plasma and platelets) in ratios (1:1:1) similar to that of whole blood or the actual delivery of fresh whole blood when blood components are unavailable. This aggressive delivery of blood products begins prior to any laboratory defined anemia or coagulopathy in patients who have been identified as having life threatening hemorrhage. This approach directly attacks the entire lethal triad which is often present in this small group of patients who are seriously wounded. However, no resuscitation strategy will work unless you are simultaneously addressing the source of the lethal triad – hemorrhage and massive contamination.

Acute Coagulopathy of Trauma Shock (ACoTS)

In civilian and military trauma populations several authors have shown a significant coagulopathy already present at the time of admission. Furthermore this coagulopathy is associated with a sharp increase in mortality. It is clear that in the injured patient Acute Coagulopathy of Trauma Shock (ACoTS) is present in about 25% of patients, it occurs very early (regardless of resuscitation), and it is lethal. DCR focuses on the early treatment of the ACoTS. The main driving force for this early coagulopathy is shock. Because of this known early coagulopathy the current state of art is to apply DCR in the management of the exsanguinating patient.

Identification of Patients Requiring DCR

It may be difficult for you to rapidly identify this group of patients. While there is currently no uniformly accepted criteria to identify the patients who will benefit from DCR, several groups have developed scoring systems (using a variety of anatomic, physiologic and laboratory variables) to correctly identify the patient who will likely require a massive transfusion. While each of these scoring systems is quite accurate, there are two scoring systems which are most applicable to the setting of a combat support hospital or forward surgical team (Table 4.1). Each of these scoring systems rely on physiologic data and each has its own limitations. The ability to apply these scoring systems will depend on your resources at your MTF. It is important to note, however, that each of these scoring systems should be used to augment, not replace, a surgeons clinical decision making. Many severely injured patients will obviously require DCR (the casualty with a systolic pressure of 50 and thoracoabdominal injures). However, many young patients in excellent shape will initially “fake you out.” These patients “look good,” right up until they undergo cardiovascular collapse. I would recommend that you use and trust your gestalt. You will find certain injury patterns help augment your decision making to initiate DCR (Table 4.2). For example, one experience based rule used in the Baghdad CSH was to give one “code red” pack (4 units PRBC, 4 units FFP) per severely mangled or amputated extremity regardless of the initial clinical appearance. Be aggressive. In our opinion, it is better to start with an aggressive hemostatic resuscitation and then shut it off early, as opposed to waiting until you are certain a patient will require a MT and starting the hemostatic resuscitation late. Again back to the philosophy “stay out of trouble as opposed to getting out of trouble.”

Table 4.1 Scoring systems to predict massive transfusion

Systolic blood pressure ≤ 90 mmHg
Heart rate ≥ 120 bpm
Penetrating mechanism
Positive fluid on abdominal ultrasound
OR
Heart rate >105
Systolic blood pressure <110
pH <7.25
Hematocrit $<32\%$
Two factors present predicts $>35\%$ incidence of MT

Table 4.2 Injury patterns consistent with need for massive transfusion

1	Uncontrolled truncal, axillary, or groin hemorrhage
2	Proximal amputation and penetrating truncal injury
3	Two or more proximal amputations
4	Severe hypothermia from blood loss
5	Extensive soft tissue defects with ongoing blood loss
6	Massive perineal wound or pelvic fracture with posterior disruption

When Does DCR Start

Ideally DCR will start at the point of injury with first responders and pre-hospital medical personnel. It is incumbent upon the medical officers to teach and direct our combat medics on the basics tenets of DCR. Tactical Combat Casualty Care principles teach that casualties with severe hemorrhage are to be transported with limited crystalloid infusion and permissive hypotension. The patient who is awake or has a palpable radial pulse does not need much, if any, crystalloid enroute to higher levels of care. Therefore the medic can focus on prevention of blood loss (tourniquet/hemostatic dressings) and hypothermia prevention. As you can see two of three important components of DCR are under the control of the combat medics. The third aspect of DCR, the rapid delivery of blood products is currently under the control of physicians at the medical treatment facility level.

Creation of DCR Protocol

The initial experience and data supporting the efficacy of a DCR strategy in the military started with the simple but somewhat radical proposition of giving more blood products and giving them earlier, and balancing the plasma and packed call products from the beginning. Figure 4.1 demonstrates a wall chart from an OR resuscitation in the Baghdad Combat Support Hospital utilizing this approach but prior to a formal 1:1 DCR protocol. Note the balance of blood products (including whole blood) creating a ratio approaching 1:1:1. Retrospective review of the outcomes using this approach has demonstrated a survival benefit and stimulated further research into the most beneficial ratios and timing of products to use.

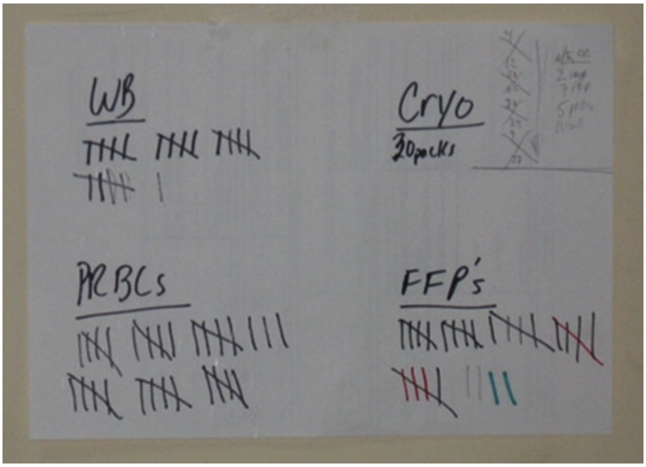

Fig. 4.1 Operating room wall chart tracking a combat trauma resuscitation in Baghdad, Iraq. Note the balanced delivery of blood products, including packed cells, plasma, cryoprecipitate, and whole blood. If whole blood is not included then platelet components must also be added

There is ongoing debate about what is the optimal ratio of blood products for the MT trauma patient. The clinical practice guidelines developed by the Joint Trauma Theater System (JTTS) advocates transfusion on a 1:1:1 ratio, essentially trying to recreate the transfusion of whole blood. Understanding the concept of a well-balanced and aggressive focused resuscitation is more important than the exact ratio, but set a 1:1 target as an easily understandable goal. Recently the JTTS has also advocated strongly the use of banked RBCs with a shelf life of less than 14 days. There is a well describe storage lesion in refrigerated red blood cells. Older RBCs when given in large amounts is likely to have more profound deleterious effects on the recipient compared to blood less than 14 days old. We advocate a "last in, first out" policy in regards to blood given in the framework of a MT protocol. This will provide the youngest blood possible in patients requiring a MT. An aggressive hemostatic resuscitative strategy can prevent development or worsening of coagulopathy during the initial resuscitation of an exsanguinating patient.

The ONLY way to consistently deliver this large amount of predefined products in a rapid fashion is to have a well thought out MT protocol in place. In the ideal setting of a theater hospital or combat support hospital this protocol should be created and monitored by a multidisciplinary team, including specialists from the emergency medicine, trauma, critical care, transfusion medicine, nursing, pathology, and anesthesia departments. The blood bank should function and be viewed as more than just a warehouse where blood products are stored and orders placed. To this aim, experts in transfusion medicine (when available) must be active participants in the resuscitation of the massively bleeding patient. In the setting of a Forward surgical team in more remote and austere locations the multidisciplinary team is going to be much smaller entity with the surgeon as the central figure in the administration of a MT protocol. In the austere location you will need to utilize whatever resources you have available to administer a MT protocol. This will also include have an organized walking blood bank process which will be discussed further in this chapter (Fig. 4.2).

Delivery of DCR

The next set of challenges is exactly how the products should be delivered. The MT protocol can be activated by the surgeon or emergency physician. Your facility should have a set policy on how the blood bank will be notified, either with a phone call, runner, or blood banks responding to the resuscitative area as a member of the team. The physician makes this decision based on the previous described scoring systems, injury patterns, or clinical acumen. A type and screen is obtained as soon as possible to facilitate type specific blood product administration. The blood bank will, upon receiving proper notification to activate the protocol, execute the MT protocol by providing a cooler with 4 units of universal donor plasma and 4 units of uncross-matched RBCs. Busy combat support hospitals will be able to keep a certain amount of thawed plasma available at all times. Keeping between 4 and 6 units of thawed universal donor (AB) plasma thawed at all times in a busy MTF will facilitate the early delivery of all blood components, and can even decrease wastage of plasma

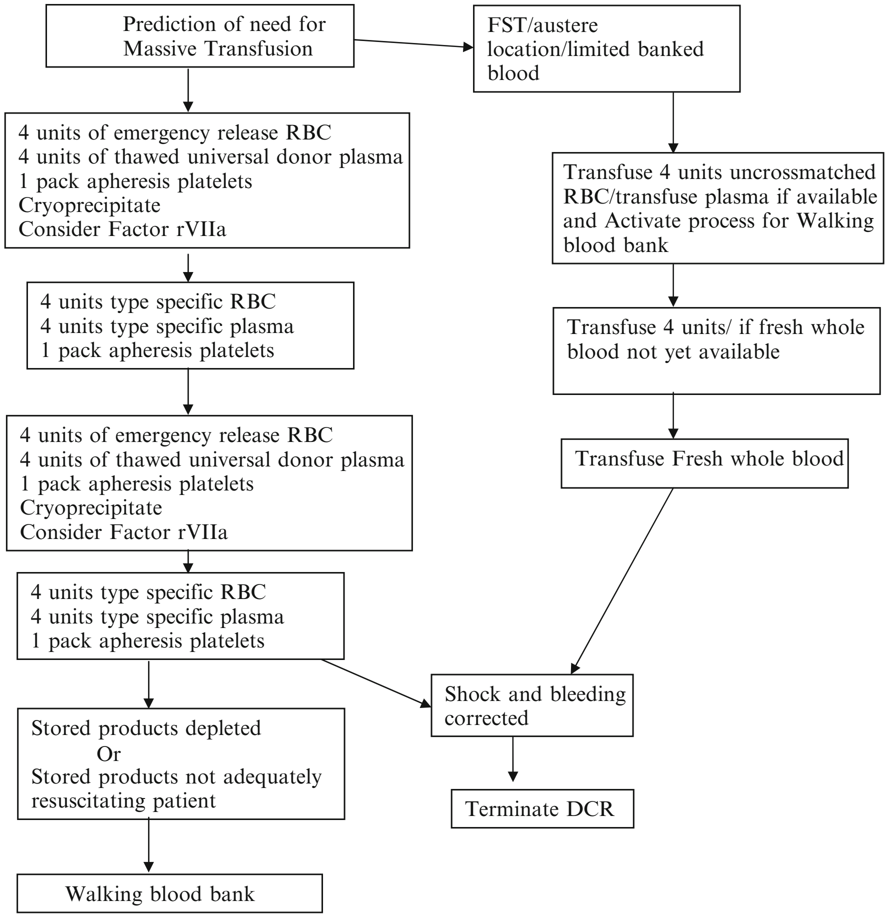

Fig. 4.2 Massive transfusion protocol for level II/III facility

products. In addition, 1 unit of apheresis platelets should be released with every cooler, but not in the cooler (refrigeration will irreversibly harm platelets). This cooler should be able to meet the patient in the emergency department or in the operating room. The blood bank then automatically begins preparing a second cooler. This cooler (and subsequent releases) contain 1 unit of apheresis platelets, 4 units of plasma, and 4 units of RBC. Also in your MT protocol should be a description of the indications and availability of recombinant Factor VIIa and cryoprecipitate. As each cooler of products are readied, the blood bank contacts the operating team to notify them that the next cooler is enroute and will inquire as to whether to continue delivery of the MT coolers. This procedure will continue with each delivery of products. A key principle of these protocols is that the blood bank does not wait to receive an order for each cooler of products, but instead continuously supplies products until the MT is stopped by the physician at the bedside.

Most MT protocols will focus on platelets, plasma, and red blood cells; often forgotten is the hypofibrinogenemia present and what product best replaces fibrinogen. There is little debate that a high ratio of fibrinogen is needed in a MT protocol. Platelets and plasma will deliver respectable amounts of fibrinogen, but are they the best source of fibrinogen? We urge you to keep cryoprecipitate (if available) in your MT protocol. A single 150 ml bag of cryoprecipitate will provide six times more fibrinogen than platelets or plasma. This 10 unit bag of cryoprecipitate is expected to raise your fibrinogen level by about 70 mg/dl. In DCR you will always be concerned with the volume of product given and cryoprecipite will provide this large fibrinogen bolus in ½ the volume of plasma and platelets, and ¼ the volume of whole blood. I would suggest using cryoprecipitate in your MT protocol by automatically delivering it in every other cooler rather than waiting for it to be ordered separately.

Termination of DCR

The delivery of blood products continues until it is determined by the operating team that the MT protocol can be discontinued. This decision will be made in the operating room or in the ICU. This decision is primarily a clinical decision made by the surgeon with the input of the anesthesia or critical care providers. The use of conventional tests such as prothrombin time, international normalized ratio, and partial thromboplastin time may not be readily available to make real time decisions. The use of rapid thromboelastography may be able to fill this void of a coagulation test with results in real time but its use has not yet been clearly defined. DCR is currently stopped when surgical bleeding is controlled. Invariably stabilization in the patient's physiology occurs at this time and normalization of conventional labs soon follows. In the near future we may have more clearly defined objective data such as noninvasive tissue oximetry or rapid bedside coagulation profiles that can aid in the decision to terminate the MT protocol. Until then, clinical accumen usually performs as well or better than most expensive and time-consuming tests.

Fresh Whole Blood

Primarily a tool of the military, the use of fresh whole blood has been used in combat theaters dating back to World War I. The US military has continued the use of fresh whole blood extensively in the ongoing conflicts in southwest Asia. The military is able to show a favorable risk benefit ratio in the use of fresh whole blood when compared to conventional blood products. Fresh Whole Blood is warm, the volume is close to 500 ml, the hematocrit is 38–50% with 150–400 K platelets, 100% coagulation activity, and 1,500 mg fibrinogen; or exactly what the patient is losing. Also fresh whole blood, as its name states, is fresh and does not possess the "storage lesion" of banked blood. The use of fresh whole blood is the ultimate 1:1:1 ratio. This use of fresh whole blood will depend on the resources you have available. Blood component availability is clearly different at the different levels of care. Combat support hospitals and Theater hospitals will likely have the only robust blood banking capability in a combat theater. Forward surgical teams will likely only have a limited supply of RBCs. Forward surgical teams typically have no more than 10 units of RBCs and may or may not have plasma. This was certainly our experience in Iraq and Afghanistan. It is in this environment that a walking blood bank becomes an excellent (and often the only) option. We have transfused over 6,000 units of fresh whole blood in the ongoing conflicts in Iraq and Afghanistan with an excellent safety profile and data that suggests a mortality benefit. However, the use of fresh whole blood is not without potential risk. There are several downsides to the use of fresh whole blood; it must be type specific, transmission of blood borne disease is rare but possible, there is a limited donor pool at small forward operating bases, and you must consider the potential deleterious effects on the donor (who usually is a soldier with a job to do). Even with these known risks we strongly encourage you to develop a walking blood bank program and to use fresh whole blood in austere settings requiring multiple transfusions or DCR.

Organization of Walking Blood Bank

The process to obtain the fresh whole blood is something that needs prior coordination with your personnel and co-located units. You must have a prescreened donor pool. This must be done prior to its need as making up a donor pool when a casualty has arrived is difficult and time consuming, resulting in unnecessary delays in the initiation of hemostatic resuscitation. Your donor pool will typically be made up of hospital, forward surgical team, or co-located unit personnel. You should always make a point of getting to know the leaders of co-located units and getting their "buy-in" for blood donations. Include them in your planning of the walking blood bank so that when it is activated they know how to be an asset. This plan would include a predetermined method to facilitate the walking blood bank. A responsible individual from your unit (not a surgeon) must have access to the blood donor pool and be able to manage the walking blood bank. You must be able to notify your operating base that you need to mobilize donors. This may be as simple has having runners that go to soldier living areas, the DFAC, or the gym. You may have public address capability to get the word out. All military personnel will have HIV screening prior to deployment and immunization against Hepatitis B but even with this knowledge you should using the rapid screening kits to evaluate for HIV, Hepatitis, and HLV. These rapid immunoassays are not as accurate as we desire but a positive result can be helpful. It is best to screen ahead of time all the possible donors with a standard questionnaire (DD572) to insure they are eligible low risk donors. This donor list will constantly have to be updated and checked as personnel will move out of your area of operations. The time frame for this will need to be determined based on the location of your MTF.

Collection of Fresh Whole Blood

When the decision to utilize fresh whole blood has been made because of lack of blood components or the blood bank has been exhausted you notify your pre-assigned individual or individuals to mobilize the donors and begin collection of fresh whole blood. The process will be set up by each facility to meet its specific needs based on the MTF location. The basic tenets will require proper identification of individuals in the donor pool, confirmation of an up to date screening questionnaire, and ensuring that they have not recently donated. If your location has the ability to screen for blood borne infectious disease this should be done, this does not obviate the need for samples to be collected and sent for testing at an approved reference laboratory. Once the patient has rapidly been deemed fit to provide a donation the walking blood bank personnel will crossmatch the donor to the recipient (dog tag blood type cannot be trusted), check the donor for significant anemia, and then proceed with collection of up to 500 ml of whole blood into a CPDA-1 bag (commercial collection bag with anticoagulant citrate phosphate dextrose adenine). Try to keep this collection area as un-chaotic as possible; a clerical error leading the transfusion of the incorrect blood type could lead to a devastating hemolytic reaction. This collection area may be within a few feet of the casualty but you still need to properly label this unit of blood. Then the unit is walked over to casualty and infused. It has been reported and I have experience with this entire process taking less than 25 min. The termination of the walking blood bank is essentially the same as what was done to stop the blood bank driven component therapy protocol. Use the combination of clinical judgment and conventional testing to determine when DCR should be terminated.

Recombinant Factor VIIa

The use of Factor VIIa has been one of the more controversial strategies that we have implemented in this current conflict, but has become widely used in both civilian and military DCR settings. Its use is still advocated by the Joint Theater Trauma Systems in its most recent updated clinical practice guideline on the use of Factor VIIa in conjunction with a massive transfusion protocol. Factor VIIa should be strongly considered in the exsanguinating combat casualty, who will likely require a massive transfusion. There does not appear to be a safety concern with the use of Factor VIIa, but many will argue that the benefits have not been clearly demonstrated either. The bottom line is it should be a tool considered in damage control resuscitation, but it is not the panacea for the exsanguinating patient.

There are several basic principles related to Factor VIIa use that you should be familiar with. It is not a substitute for surgical control of bleeding, and should not be used to temporize or delay going to the OR. If the patient has no platelets or clotting factors, then Factor VIIa will not work and is just an expensive placebo. You should be giving plasma and platelets prior to or concurrent with the drug dose. A dose of 100 mcg/kg is easiest to remember, and should be given as an IV bolus. You should strongly consider giving Factor VIIa in the patient with diffuse coagulopathic bleeding, worsening coagulopathy despite appropriate DCR, pre-existing coagulopathies or anticoagulant use with traumatic bleeding (particularly intra-cranial hemorrhage), or in very austere locations with limited blood products or anticipated prolonged transport times. Try to achieve a pH of greater than 7.2 prior to administering the drug, but a pH of less than 7.2 is not an absolute contra-indication and you should still get some drug activity in this environment. Repeat doses may be given as needed, but should not be given if there was no evidence of any response to the first dose or as a "last-ditch" effort in the already exsanguinated patient.

The Aftermath of DCR

The concept and execution of DCR has been praised as one of the biggest recent advances in combat and trauma medicine, but it is not "magic." It will not salvage all bleeding patients or make up for lapses in decision making and surgical technique. You must also be aware of the short and longer term implications of a DCR strategy. It will tax your blood bank, particularly if used indiscriminately. The ideal ratios and types of products to administer are unknown. We still do not know the full impact of transfusing additional blood products on longer term complications such as infectious disease transmission, nosocomial infection rates, and immunosuppression. It does appear that the rates of ICU complications such as ARDS and multi-organ failure are increased with DCR, likely due to the salvage of very sick patients who would not have previously survived surgery. Plasma transfusion appears to be the driving force in transfusion related acute lung injury (TRALI), so the incidence can logically be expected to be higher in DCR patients. It appears that the incidence of TRALI can be decreased by using male only plasma donors (decreased antibody levels compared to multiparous female donors), but this is often not an option due to supply and demand. You should be aware of all of these factors to best utilize this important and life saving strategy.

Forward Surgical Team Specifics

Some Forward Surgical Teams will be co-located with Level 3 facilities (Combat Support Hospital) or with medical companies that will provide them material and support. However in remote theaters, such as Afghanistan, FST's are often in austere locations and may be split between two locations leaving just ten personnel with very little logistical support. This may seem exceedingly small amount of resources in one location, but these small remote teams have performed well. In regards to DCR in a remote location the physician will not have the robust blood bank to deliver component therapy to casualties. Fresh whole blood will be utilized in the most seriously injured who you suspect will require a massive transfusion. But with proper preparation and utilization of co-located US personnel these teams can handle the most seriously injured combat casualties.

In conclusion, the key concept in DCR is to be aggressive with component therapy and/or whole blood. All the available information suggests that this has saved many lives on the battlefield. In our opinion, it is better to start with an aggressive hemostatic resuscitation and then shut it off early, as opposed to waiting until you are certain a patient will require a MT and starting the hemostatic resuscitation late. The triage philosophy "stay out of trouble as opposed to getting out of trouble" holds true in these situations.

Chapter 5
To Operate or Image? (Pulling the Trigger)

Matthew Martin

Deployment Experience:

Matthew Martin — Chief of Surgery, 47th Combat Support Hospital, Tikrit, Iraq, 2005–2006

Chief, General Surgery and Trauma, Theater Consultant for General Surgery, 28th Combat Support Hospital, Baghdad, Iraq, 2007–2008

BLUF Box (Bottom Line Up Front)

1. There is no more critical early decision than whether to proceed immediately to the operating room or to perform more evaluation and imaging.
2. Time is your enemy; start the clock on patient arrival and proceed as if every minute is another unit of blood lost.
3. Patients die in CT scan, therefore a hypotensive trauma patient belongs in the operating room ASAP.
4. Detailed head to toe imaging is not an emergency, and not required to manage nearly all life-threatening injuries.
5. Unless you have clinical evidence of elevated intra-cranial pressure, the chest and abdomen trump the head injury and a head CT scan can wait.
6. Trust your physical exam, your training, and your instincts.
7. Discard the civilian blunt trauma mindset – it will leave you with a dead patient.
8. You can identify and localize exsanguinating hemorrhage in 5 min or less without leaving the resuscitation room or operating room.

"God gave you ears, eyes, and hands; use them on the patient in that order."

William Kelsey Fry

One of the common attributes of great trauma surgeons is that they seem (to us mere mortals) to have the ability to magically sort out who needs emergent intervention without all of that "new-fangled technology" that has replaced the physical examination and clinical judgment. I had the great opportunity to train under one

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such legendary figure, and quickly realized that the strongest predictor that the patient needed to go emergently to the operating room was when he pulled his cloth scrub cap out of his back pocket and put it on. We all learned to watch closely for this tell-tale sign, and how incredibly accurate it was for predicting life threatening injuries just by simple observation and examination. However, with close observation I came to realize that he was able to do this in large part by applying a basic set of rules and principles governed by common sense and a deep understanding of trauma mechanisms and anatomy. Although no chapter or guidelines can hope to replicate that level of judgment built on decades of experience and hard-earned lessons, you can easily adopt the principles and algorithms outlined here to manage the most challenging group of patients you will ever encounter: combat trauma patients.

The sharp decline in penetrating trauma volume and the increase in non-operative management of most injuries have inadvertently created a widespread disease pathology among surgeons and surgical trainees: *CATatonia*. I define this as "the inability to make definitive management decisions without the use of detailed computed tomography imaging, coupled with a fear of the "exploratory" operation". If there is one over-riding principle to guide you in managing combat trauma, it is to abandon or adjust the civilian trauma algorithms that you have learned. Combat trauma is in many ways the polar opposite of civilian trauma – penetrating mechanisms predominate, severe and multi-compartment injury is more common, and the majority will require some form of operative intervention. The goal of this chapter is to help you make the early and critical decision of "what next?" after the initial trauma evaluation, and learn to be comfortable "pulling the trigger" to go to the operating room even in uncertain situations. In the stable patient these approaches may save you time and resources; in the unstable or bleeding patient, these approaches may save his or her life.

The Stable Patient

Even in a combat or disaster setting the majority of patients that reach your facility alive will present with relatively stable hemodynamics. The decision here to proceed with further imaging or go to the operating room has much less urgency than in the unstable patient, but can still result in added morbidity or mortality. Remember that young and healthy trauma victims (such as soldiers) can maintain surprisingly normal vital signs with large volumes of hemorrhage right up to the point of rapid decompensation. You should still evaluate these patients as if they potentially have ongoing hemorrhage. Do not move them for imaging until you are satisfied that they are truly stable and do not have large volume chest, abdomen, or pelvic bleeding. Your physical exam and basic imaging (x-ray and ultrasound) evaluation for hemorrhage is described in detail later for section "The Unstable Patient" and in Fig. 5.1.

Assuming this workup is negative, you now have to decide on performing more imaging studies or moving to the operating room. This decision should be based on the patient's identified injuries as well as the likelihood of unidentified injuries and their urgency or lethality. If the patient has no identified injuries that require

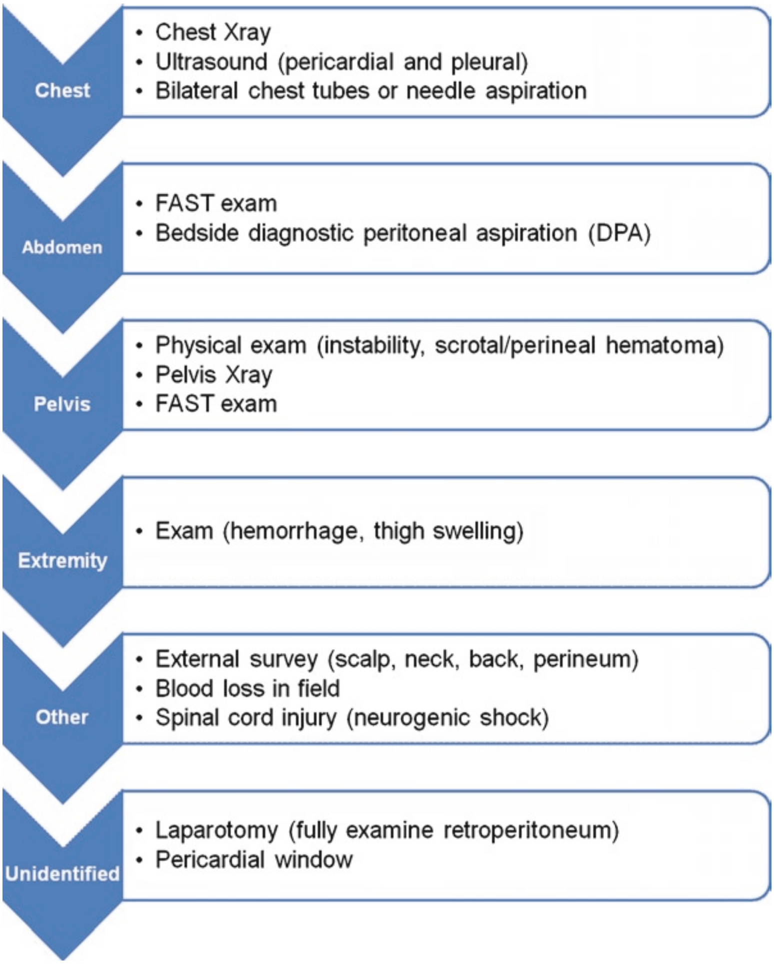

Fig. 5.1 Approach for rapid identification of hemorrhage in the unstable trauma patient

an operation then proceed with imaging as dictated by the mechanism and initial evaluation. If the patient has one or more injuries that clearly will require operative intervention then there are three factors you must weigh into your decision; (1) the nature and urgency of the operative injury, (2) the other areas of potential injury, and (3) the lethality of these potential missed injuries. In the end these decisions should all come down to an educated analysis of the odds and probabilities of each course of action and choosing the one with the greater upside and the more acceptable downside.

If you do move directly to the operating room, you should always maintain a plan for how you will proceed in the event of an unexpected decompensation or manifestation of injury in another anatomic area. For sudden hemodynamic instability, bilateral chest tubes with a laparotomy and pericardial window rules out almost all potential operative sources of occult large volume hemorrhage. If the patient manifests sudden evidence of neurologic deterioration due to rising intracranial pressure (dilated pupil, hypertension/bradycardia) then you must decide between terminating the procedure and obtaining an emergent head CT or performing a concurrent blind craniotomy or burr holes. See Chap. 24 for more detailed discussion of this scenario. Calling for help is the first and best maneuver you should perform in that situation.

If you decided to perform some additional imaging on a stable patient before proceeding to the operating room then keep these principles in mind. The patient can deteriorate at any point, and will usually choose the least opportune time to do it. Make sure you have continuous observation and monitoring throughout the imaging process. Be fully prepared to pull the patient off of the imaging table and move to the operating room if there is any deterioration. Only perform the studies that you absolutely need prior to the operating room, and prioritize the order of those studies in case of clinical deterioration and termination of imaging.

The "Rule Out" Head or Spine Injury

One of the most frequent refrains overheard at heated trauma M&M discussions is "I was concerned about a severe head (or spine) injury". This is usually in response to a question about why a particular patient bled to death on the CT table while obtaining detailed images of a normal brain or non-operative brain injury. This is even more of an issue in the combat or disaster scenario, where severe and multisystem injuries are the norm. The lull of the "quick head CT" has lured many a trauma surgeon to disaster, so be wary. Unlike almost all other areas of surgery, in trauma you must often proceed based on incomplete and imperfect information. In these scenarios you have to then fall back on your common sense augmented by knowledge of odds and probability. In a patient with both head and truncal injuries, the overall odds of performing a life-saving surgical intervention are always going to favor addressing the truncal injuries as the priority. Patients who require both a therapeutic truncal procedure (laparotomy or thoracotomy) and craniotomy are fortunately extremely uncommon. For combat or disaster type injuries, the patient who is awake, alert, and talking to you is exceedingly unlikely to have any type of operative brain injury and a head CT should be a low priority.

In the patient who is unstable or quasi-stable, the only thing that should make you consider obtaining a head CT before moving to the operating room is evidence of catastrophic intracranial hemorrhage. Know how to recognize the clinical signs of rising or elevated intracranial pressure. This includes a depressed GCS (<10) or a rapid decline in mental status along with one or more characteristic physical exam findings; dilated and fixed pupil(s), motor posturing, hypertension and bradycardia with altered respirations (Cushing's triad). If the ICP is elevated enough to cause these signs, then there will always be a depressed mental status! Therefore, a unilateral dilated pupil in an awake and alert patient is not from elevated ICP and herniation. Hypotension in these patients is from hemorrhage until proven otherwise, and the best thing you can do to help preserve neurons is control bleeding and reverse the hypotension.

Spine imaging in the severely injured patient is a pure time-waster. If you have time to waste, then image the spines. Otherwise, maintain spinal precautions while you deal with life or limb threatening injuries and fully evaluate the spine later. Even in a patient with a clear spinal cord injury, you are highly unlikely to find anything on CT scan that will change your early management or operative priorities. Remember that the best thing you can do for your patient's spinal cord is to prevent hypotension and hypoxia – and this is done in the operating room and not the Radiology Department. Once you have hemorrhage and contamination controlled you can deal with the brain or spine injury. Involving your neurosurgeon or spine surgeon early (if you have the luxury of having one) can be a great help, but always maintain focus on your management priorities and the big picture.

The Unstable Patient

This is the scenario where those key early decisions truly determine life or death. The hemodynamically unstable combat trauma victim is bleeding to death – period, end of story. If you have an easily identified and obvious source of the bleeding, such as bilateral leg amputations, then you can proceed with temporary (tourniquet) followed by definitive (surgical) hemorrhage control. But what do you do with the patient who has holes everywhere and is hypotensive? The first step is realizing that this patient almost certainly belongs in the operating room, and as soon as possible. Start to mobilize your resources in that direction to get things moving. Do not take this patient to the CT scanner – even for just a "quick head CT". You will often regret it, while you will rarely regret moving to the operating room. Now you need to figure out where the bleeding is and do it quickly. You should be able to do a rapid head to toe survey for hemorrhage in about 3–5 min using only physical examination, basic x-rays and/or ultrasound, and a 20 gauge needle.

Figure 5.1 demonstrates a simple algorithm for the approach to this patient. This is based on two main principles; (1) there are a limited number of body compartments that can contain enough blood to exsanguinate, and (2) the signs of exsanguinating hemorrhage in any of these compartments are not subtle. If you have a normal physical examination and x-ray or ultrasound of that compartment, it is highly unlikely to be your bleeding source. The cranium cannot contain enough blood to cause hypotension from hemorrhage and hypotension from brain injury should be a diagnosis of exclusion, not a primary hypothesis. However, beware of the bleeding scalp wound or skull fracture building up an unrecognized pool of blood on the floor.

A normal chest x-ray essentially rules out the thoracic cavity, so train your x-ray techs to fight their way in and get the film. Ultrasound of the chest is highly reliable (in skilled hands) for hemothorax and pneumothorax and easily integrated into the FAST exam (see Chap. 6). In addition, the pericardial view should identify any effusion that has become large enough to cause tamponade. If you are not skilled at abdominal and thoracic ultrasound, then getting skilled should be a priority. Alternatively, bilateral chest tube placement or bilateral needle aspiration (fifth intercostal space, mid-axillary line) can make the diagnosis and potentially be therapeutic. Physical examination of the abdomen and pelvis may identify massive distension or pelvic bony instability, but is not highly sensitive. A normal pelvis x-ray rules out hemorrhage from pelvis fractures. A negative FAST exam can provide reassurance, but is *not definitive* for ruling out the abdomen. If no other source has been identified and the patient remains hypotensive, perform a diagnostic peritoneal aspiration (DPA) using a 20 gauge needle. Blood will accumulate in the paracolic gutters and pelvis, so aspirate one or more of these areas and if gross blood is found then proceed with laparotomy. Do not worry about damaging the bowel with your aspiration; a 20 gauge needle hole will seal itself. Even if all of these are negative, the retroperitoneum remains a potential source of bleeding. However, most retroperitoneal injuries that bleed enough to produce instability will have ruptured into the peritoneal cavity and produce positive findings on the workup outlined above.

If no obvious source has been identified at this point, then begin looking for less likely candidates. The only possible extremity compartments that can hold enough blood to produce shock are the thighs, and this should be obvious on exam. A full external survey should be performed including the back and the perineum – both potential areas for large volume hemorrhage. External blood loss prior to arrival should be considered, but this usually corrects rapidly with resuscitation. Neurogenic shock from spinal cord injury should be considered only if there is paraplegia or quadriplegia present, and after ruling out any other surgical cause. Finally, if the patient remains unstable from an occult source then proceed to the operating room for abdominal exploration and you should also consider performing a pericardial window.

The Sirens of Combat Trauma Imaging (Specific Pitfalls and How to Avoid them)

In Greek mythology, the Sirens were creatures who would use their seductive voices to lure unsuspecting sailors to doom on the rocks surrounding their island. In combat trauma you must resist the siren song of those around you (and in your own head) luring you to apply the "usual" trauma imaging evaluation to all patients. This often takes a concerted effort on your part and may result in some consternation from those who apply a universal cookie-cutter approach to trauma. Although the individual circumstances and different injury patterns you will encounter are infinitely variable, I will provide you with several specific examples that seem to be often repeated.

1. *The mangled extremity* – this is the patient with one or more mangled or amputated extremities. They usually have tourniquets on and may be stable or quickly stabilize with initial resuscitation. They clearly need to go to the OR, but often are brought for a whole body CT. Pitfalls are that their wounds will continue to bleed, or will start to rebleed as their blood pressure rises with resuscitation. In addition they often need to be intubated to facilitate pain control and positioning for the CT scan, so you have now lost the physical exam or they become severely hypotensive with induction. Most of these patients should go right to the operating room after the initial trauma evaluation and bedside imaging, and postoperative CT scans can be obtained if needed.
2. *The pin cushion* – this is the patient with multiple small fragment wounds to the trunk and extremities. CT scan is very useful in these patients for differentiating superficial wounds from deeper penetration and injury, particularly in the neck. However, the patient with these wounds and significant abdominal pain or tenderness does not need a CT scan before laparotomy. A normal chest x-ray rules out any immediately life threatening thoracic process, so the chest CT can wait. Similarly, a normal pulse exam is very reliable for ruling out a *significant* extremity vascular injury and does not require time consuming CT angiography prior to dealing with more pressing injuries.
3. *The massive perineal wound* – these will be some of the most difficult patients you will ever manage, and can bleed to death from these wounds in a matter of minutes (Fig. 5.2). Unfortunately they are becoming more common due to explosive devices detonating under seated vehicle passengers. These patients belong in the operating room as soon as possible and should almost never be delayed to obtain more imaging. The abdominal exam, FAST exam, and pelvis x-ray should provide all the information you need to proceed to the OR for wound management

Fig. 5.2 Massive perineal blast wound with destruction of the sphincter complex and exposed distal rectum. These patients should be brought immediately to the operating room to prevent rapid exsanguination

with or without laparotomy. Most of these are going to require a laparotomy for colonic diversion anyway, so the abdominal CT is redundant and unnecessary. If CT is absolutely necessary, you must be able to watch for hemorrhage from the perineum while the imaging is being done.

4. *The Single Gunshot Wound (GSW)* – although this patient is becoming less common than the blast injured patient, any combat situation will provide ample ballistic injuries to manage. The majority of these will require operative management of the injured area, and do not require any more extensive imaging than plain films. I often hear the justification of "unpredictable trajectories" as an indication for extensive CT imaging. Although I agree that the projectile may take an unusual path due to patient positioning during injury or bony deflection, the bullet will still obey all the laws of physics. It will not stop in mid path, reverse course, or make hairpin turns into another cavity. The following scenarios involving isolated GSWs almost never need CT imaging and should be taken expeditiously for operative intervention:

   Neck wound with hard sign of vascular or aerodigestive injury

   Chest wound with large volume hemorrhage (initial >1,000 cc or continued bleeding)

   Abdominal wound with evisceration or peritonitis

   Extremity wound with hard sign of vascular injury or compartment syndrome

Final Points

Expert trauma management is all about prioritization, anticipation of worst-case scenarios, and playing the odds. Not just with the initial ABCDs of the evaluation, but in every subsequent decision or intervention you make in the acute setting. In these chaotic situations with imperfect and incomplete information, you will never be right 100% of the time. By adopting an approach that appreciates and anticipates both the positives and negatives of each decision, you can maximize your outcomes while also minimizing the impact of any adverse events. The usual slow, methodical, and exhaustive evaluation schemes used in diagnostic medicine and civilian trauma will not serve you or your patient well, so as Basil King famously said; "Be bold, and mighty forces will come to your aid".

Chapter 6
Ultrasound in Combat Trauma

Benjamin Harrison

Deployment Experience:

Benjamin Harrison EMT Chief and Theater Consultant for Emergency Medicine, 28th Combat Support Hospital, Ibn Sina Hospital, Baghdad, Iraq, 2006

BLUF Box (Bottom Line Up Front)

1. Never delay transport to OR for any radiologic study in these patients with clear indications for immediate operative intervention, but Ultrasound (US) can give quick and useful data in patients who are foregoing CT scan enroute to the OR.
2. US is much more sensitive than supine CXR in blunt/penetrating trauma in experienced hands and US should not be delayed for plain radiography in most situations.
3. US should be performed after the ABCs have been addressed: think “ABC-U.”
4. Repeat EFAST is good; do it early and, if normal, repeat it since hemoperitoneum and hemothorax may take time to accumulate.
5. US is operator dependent, so always consider the skill and experience of the US operator and his/her confidence level prior to interpreting US findings.
6. Injuries on today’s battlefield often include varying combinations of burn, penetrating and blunt trauma. In severely burned patients, the EFAST can quickly identify other life-threatening injuries as you aggressively manage the patient’s thermal wounds.
7. US can give vital information that providers can use in making immediate triage decisions in the trauma patient(s) who is in extremis or full arrest.
8. Use down time during your deployments to get comfortable (or proficient!) with US.

“*Failure to immediately recognize and treat simple life-threatening injuries is the tragedy of trauma, not the inability to handle the catastrophic or complicated injury*.”

F. William Blaisdell

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Why Ultrasound?

Ultrasound is an important part of the initial trauma workup, no matter the setting. Most surgeons will be practicing at a Combat Support Hospital (CSH) in theatre; however, as a part of a FST you might not have a CT scanner available. In austere scenarios, US can be invaluable in directing resuscitative and operative management, but US should also be a part of the CSH or trauma center evaluation. Admittedly, many civilian trauma centers have such quick access to CT scanning that US is largely bypassed with the advent of the "pan-scan." With multiple patient and mass casualty scenarios quickly overwhelming CT capabilities; however, US can be crucial in getting the trauma team useful information quickly.

Ultrasonography as a tool in wartime trauma management really just started to gain widespread use during the First Gulf War, and it is finding its way closer to the frontline as OIF/OEF continues. While most recently graduated surgeons and emergency physicians have seemed to embrace US, it can be challenging for providers who did not receive residency training in US. Most are familiar with US, but lack the training and hands-on experience to really become adept at this skill. That's the rub; not only does the trauma doctor need to know how to interpret and act on US images, he/she must also learn the skill of obtaining usable images *in an acceptable amount of time*. You do not need to be an expert to use US, but the knowledge and skills will degrade if not practiced continually.

This brief chapter is not designed to take the place of proper US training or an US course, but rather to give an overview and some references/reminders for US applications. I personally was comfortable and competent to perform US, yet did not feel that I was truly proficient until I had performed dozens of extended trauma ultrasound exams during my first month of deployment. There is a big difference between thinking a patient probably has a pneumothorax on US, and actually knowing it exists (*and* placing a chest tube based on your US findings without obtaining other radiologic studies). If you are a deploying surgeon or physician who will be managing any type of combat casualties, then you *must* become familiar with the basics of ultrasound and the standard trauma exams (focused assessment with sonography for trauma or FAST) *before* you deploy. With very little additional time and effort, you can add the skill set of basic thoracic imaging to perform the extended FAST exam (EFAST).

The great news is that most of us will be deployed with easy access to an ultrasound machine and deployment is the perfect time to refine/maintain our US competency. Tap into the US expertise of skilled ultrasonographers in your unit, be it the radiologist, emergency physicians or trauma surgeons. Apply the skills you know and practice repeatedly on your medics or EMT patients until you feel very comfortable with the probe positioning and the images you obtain. If we cannot do this quickly in a trauma resuscitation, team members can get annoyed and the slow ultrasonographer usually gets pushed out of the way. We must be able to obtain the information in a timely manner, or this modality isn't very helpful. If time allows, as you refine your skills, go back to the stable trauma patient who has already had a positive CT finding and perform an US. Alternatively, bring the machine to the ICU and perform exams on patients with known intraperitoneal fluid (usually postop) or cardiac effusions. Recognizing positive findings and learning how intraperitoneal blood, pericardial blood/fluid or intrathoracic blood/air looks on US is a critical part of attaining proficiency. Most of us won't attain proficiency until we have performed and interpreted numerous positive EFAST scans, in addition to our "training" scans on normal patients.

Have your unit purchase at least one US machine *prior* to deploying; it will be invaluable no matter what the combat setting. If deploying with a CSH, I highly recommend getting your Command and supply personnel to help purchase multiple units. While deployed with a CSH, we had two older US units in the Emergency Room that were in constant demand from intensivists, radiologists and cardiologists. There were times when we needed them for EFAST in critical patients but they were being used in the ICU, so think about this ahead of time since it can be very hard to get additional or upgraded US units in theater. Also have your supply folks consider the wear and tear and coordinate with the manufacturers for replacement parts and repair ahead of time.

Advantages of US

1. Essentially replaces DPL (quicker, non-invasive, not overly sensitive) in most scenarios.
2. Tells you if there is significant blood in the abdomen, chest or pericardium, allowing you to more quickly perform necessary interventions (including exploratory laparotomy or emergent thoracotomy).
3. Identifies pneumothorax quickly and easily. This is very useful in managing patients in the field, or at a level I or II facility where US is the only available radiologic modality.
4. Show us what is happening at a given point and time. Serial EFAST scans, after rolling the patient or after placing them in Trendelenburg position, increases the sensitivity in the stable patient.
5. Done at quickly at bedside; no need to send unstable patients to the "black hole" of radiology. Gives additional, immediate data in patients being taken straight to the OR.
6. No contrast or radiation exposure.

Disadvantages of US (for the Average Ultrasonographer)

1. May miss small hemoperitoneum (about >100–200 ml needed to be seen with US)
2. Does not normally identify the site of intraabdominal bleeding

3. Does not show hollow viscus injuries well
4. Does not reliably show retroperitoneal bleeding
5. Does not tell us if free fluid present is blood, ascites, urine or (in chest) pleural effusion
6. Relatively insensitive in pediatric patients (although helpful if positive)
7. Unable to perform US in certain patients due to body habitus, air, etc…

How to Perform an EFAST

The EFAST (Extended Focused Assessment with Sonography in Trauma) is the basic exam used to evaluate thoracoabdominal injury. While there are different variations on the order of performing the views, I will describe the way I do it. There are four basic views that are usually obtained in the traditional FAST exam: right upper quadrant (RUQ), left upper quadrant (LUQ), pericardium, and pelvic. The "E" or extended portion of the EFAST came about after thorax scanning for pneumothorax was added later. Evaluation for hemothorax is more commonly being performed as part of the EFAST. Search for blood above the diaphragms as you do the RUQ/LUQ abdominal views. Below is an explanation of basic techniques for obtaining views; however, realize that the EFAST is a dynamic process that takes into account multiple images of each view as we look for air and blood. Slide the probe around and look at each view from different angles to increase your sensitivity. Placing the patient in Trendelenburg may increase the sensitivity of your RUQ view if you are unsure if there is fluid on the pelvic view. Also, recall that a negative EFAST might still be missing accumulating blood in the intraperitoneal space and that results should not be used in isolation when managing a trauma patient. EFAST should be repeated in certain clinical settings if initially negative. We should view US as a dynamic process and interpret results in light of the patient's clinical picture and stability.

Basic Terms and Knobology

Not to get too technical, but we need to use certain terms to communicate in US lingo. Basically, an US probe (transducer) pushes out acoustic waves and detects reflected waves (from dense matter) that bounce back to the US probe. US waves that pass through homogenous material do not reflect back to the probe and are termed *anechoic* (completely black, implies homogenous fluid such as urine, unclotted blood, or water). Most other organs and structures in the body are represented in shades of gray (or degrees of echogenicity), as sounds waves pass through them with varying degrees of reflection back toward the probe. The more *hypoechoic* the structure, the more fluid filled and homogenous they are (and the darker they appear on US). *Hyperechoic tissue* is generally more dense and reflective (higher impedance, like bone), showing up white or lighter-gray on US. Isoechoic means that adjacent tissue has similar appearance (or echogenicity), due to similar degrees of impedence. Examples of varying degrees of echogenicity, from darker to lighter (anechoic to hyperechoic) are: water-fat-liver-tendon-bone). Remember, air is the sonographer's enemy; sound waves transmit poorly through air (due to scatter) in comparison to fluids and solid organs and thus limits our exams when present. Large amounts of air in the intestine can render an abdominal US meaningless if we cannot navigate around it. Conversely, echodense structures such as the liver provide excellent sound wave transmission and can serve as a window to examine deeper structures.

The knobs on the US machine vary greatly depending on the make/model of the machine, so get to know your machine so you can tell which knob does what. The most important knob (other than the power switch) is the gain. *Gain* is basically how much amplification comes from the transducer. The more you turn it up, the more white all structures will appear on the screen. Inappropriate gain can make interpretation difficult, so adjust the gain until images look "about right;" (yes, this is subjective and the more scans you do, the better idea you will have of what your images should look like). The other important knob to find is the depth. Adjust the *depth* knob to ensure the area you are imaging fits in the middle of the screen and isn't too deep (image of interest appears small at the top of the screen – hard to see details) or too shallow (area of interest extends beyond bottom of screen). There are usually markers on the side of the image that give a scale in centimeters for depth. A normal starting depth for the abdominal portion of the EFAST is in the 12–19 cm range. The other buttons can be useful in some situations, but not mandatory for doing a basic EFAST exam.

Probes come in different sizes, shapes and design. The higher the frequency probe, the less penetration and more detail and resolution you get. Most EFAST views should be performed using low frequency probes (2–5 MHz), while the high frequency probes (5–10 MHz) are great for pneumothorax studies and superficial applications (soft tissue, vascular access). I prefer a high frequency probe for pneumothorax scans, but the abdominal/low frequency probe can also be utilized. I recommend using the smaller footprint phased array transducer (looks like a square box) to allow shooting through ribs without interference for the EFAST views, although some prefer the larger, curve shaped low frequency abdominal probe because of better image quality. All probes have a *transducer indicator* for orientation; the image on the US screen has a colored dot that correlates with the end of the transducer that has the marker. The general convention is to orient the indicator toward the patients' right side (for transverse/axial imaging), or towards the patients' head (for sagittal and coronal imaging).

It helps to be familiar with the characteristics of each probe and choose the one with which you feel most comfortable when performing an application. As an aside, make sure the trauma team members know how to clean the probes and to keep them off the ground and secured when moving the unit. A damaged probe can cost tens of thousands of dollars if the cord is run over or the probe dropped.

Abdomen

RUQ (Perihepatic or Hepatorenal) View

Free intraperitoneal blood is most often identified in Morison's pouch, between the liver and right kidney; this is a relatively easy site to see abnormalities for even the novice sonographer. This view reliably detects volumes of about 600–700 ml of blood; 400–500 ml if the patient is in Trendelenburg. Place the probe longitudinally (with the marker dot directed cephalad) near the mid-axillary line between the 8th and 11th interspaces. This is the *intercostal* approach, which I prefer. The *subcostal* technique may require the patient to be cooperative and take deep breaths, which many cannot. Angle, slide or rock the probe until the right kidney is seen in a longitudinal (coronal) plane, with the hyperechoic, hepatorenal peritoneal reflection in between (*see* Fig. 6.1 *for normal RUQ view*). The normal appearance (negative exam) should look like the kidney capsule is directly abutting the liver edge with nothing in-between. Intraperitoneal blood appears (acutely and classically) as an anechoic (black) stripe between the liver and kidney (Morrison's pouch) and may have varying degrees of echogenicity based on degree of clot and fibrin stranding (*see* Fig. 6.2). To assess for other bleeding sites, direct or slide the US probe cephalad and posterior, through and above the diaphragm, in a coronal plane. This allows you to assess for bleeding within the liver parenchyma, and subdiaphragmatic space, as well as for hemothorax above the diaphragm. Blood or fluid in the thorax will have a V-shaped appearance, while subdiaphragmatic blood will be crescent-shaped (*see* Fig. 6.3). Sensitivity/specificity for detecting 20–50 ml of blood in the hemithorax is >95%, much better than supine CXR at those volumes. Remember on both the RUQ and LUQ views that identifying blood in the chest requires dynamic imaging to identify the location and movement of the diaphragm during normal respirations.

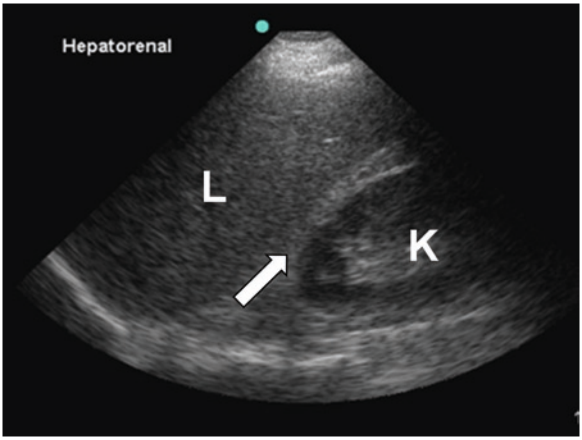

Fig. 6.1 Normal right upper quadrant (hepatorenal) view. Note the normal appearing hyperechoic line (*arrow*) between the liver (L) and right kidney (K)

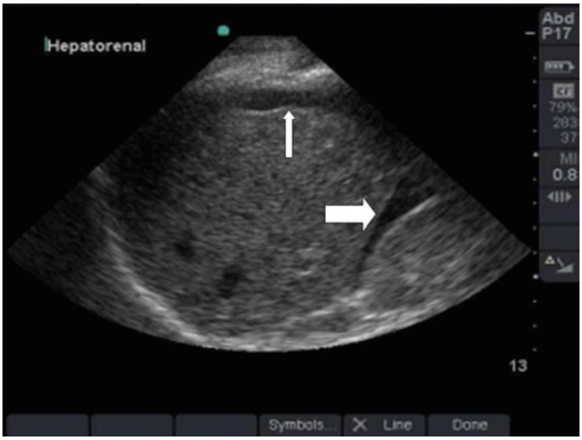

Fig. 6.2 Positive right upper quadrant scan, with *dark stripe* of blood in Morison's pouch (*large arrow*) and above liver in the right subphrenic space (*small arrow*)

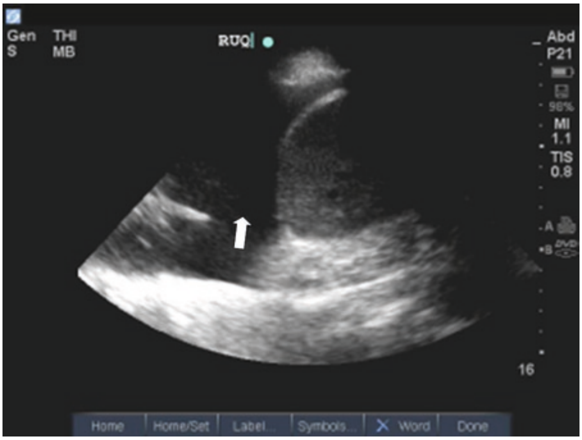

Fig. 6.3 Right sided hemothorax, with hypoechoic collection of blood seen above diaphragm (*arrow*)

LUQ (Perisplenic or Splenorenal) View

This is an intercostal approach and, when placing the probe, think "more posterior and more superior" in comparison to the RUQ view. I reach over the patient and place my right knuckles on the gurney and start near the left posterior axillary line at 9–10th interspace, with the marker dot pointed cephalad, to view the splenorenal junction (*see* Fig. 6.4 *for normal LUQ view*). Sweep the probe anterior and posterior, as well as cephalad and caudal, to look for bleeding from a splenic injury. Similar to the RUQ view, you will look for any blood (black stripe) building up between the kidney and spleen. But you are not done there. Remember that on this side blood most often collects in the subphrenic space, so it is vital to also look above the spleen (*see* Fig. 6.5). In doing so, we can see hypoechoic/anechoic fluid both

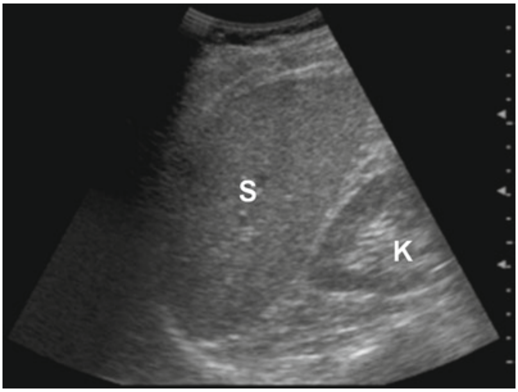

Fig. 6.4 Normal left upper quadrant (splenorenal) view showing the spleen (S) and the left kidney (K). Note the curvilinear, *hyperechoic line* (diaphragm) above the spleen

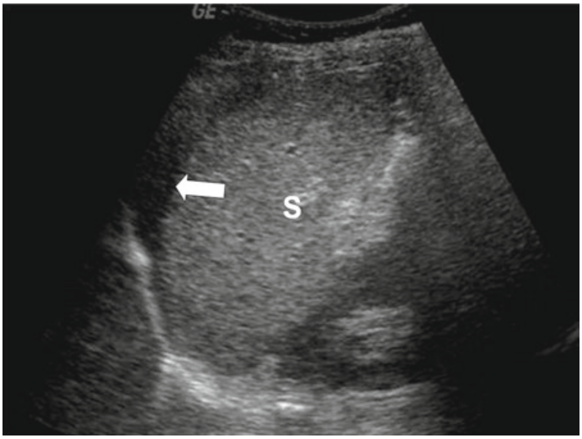

Fig. 6.5 Positive left upper quadrant scan, with *dark stripe* of subdiaphragmatic blood seen above the spleen (*arrow*). Note the crescent shape of blood, as compared to hemothorax, which has sharper or "v" shape

below the diaphragm (hemoperitoneum) and above it (hemothorax) all in one view. While not the primary purpose of EFAST, splenic parenchymal injury can also often been visualized as you perform this view.

Pelvic View

In most patients, this is the most sensitive view in detecting intraabdominal bleeding and only about 100–200 ml is needed for a positive scan. Since a full bladder helps image quality, perform EFAST before Foley catheter placement, or after clamping the catheter and infusing 200 cc of fluid into the bladder. Place the probe just above the symphysis pubis in the midline and angle the probe caudad to look into the pelvis. Obtain both *longitudinal* (probe indicator pointed cephalad) and *transverse* (probe tip to the patient's right) views (*see* Fig. 6.6 *for normal view*) In females, fluid is seen just

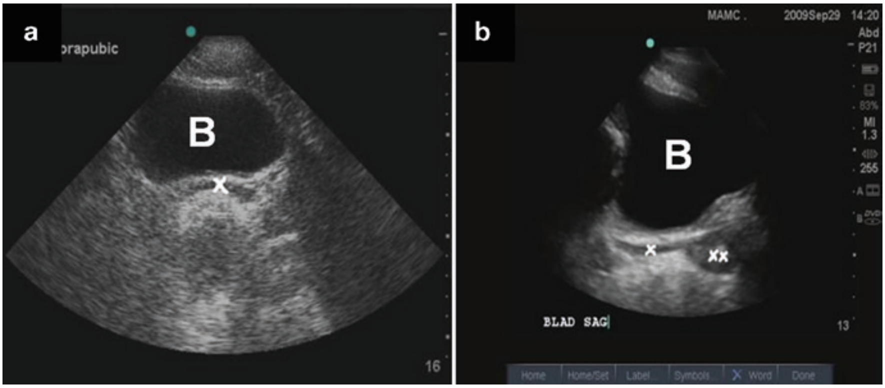

Fig. 6.6 Normal transverse (**a**) and longitudinal (**b**) pelvic views in a male patient (B = bladder, x = seminal vesicles, xx = prostate gland)

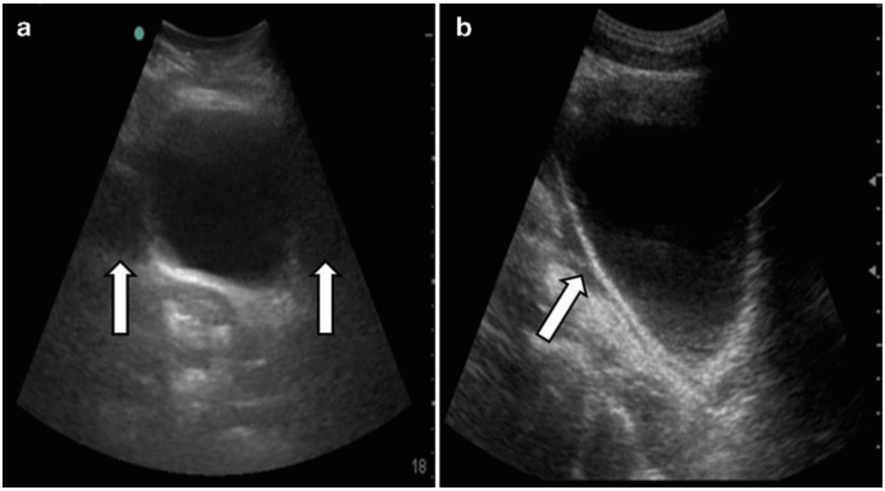

Fig. 6.7 Positive transverse (**a**) and longitudinal (**b**) pelvic views. Hypoechoic blood is seen on either side of the larger, anechoic (*black*) urine-filled bladder in (**a**) (*arrows*). In (**b**), the *dark stripe* of blood outside the bladder (*arrow*) tracks along the intestines and the posterior bladder wall, unlike the rounded edges of urine contained within the hyperechoic bladder walls

posterior to the uterus if a small amount, but may surround the uterus if there are large volumes. In males, fluid is seen behind or above the bladder (*see* Fig. 6.7). A common false positive comes from over-reading the seminal vesicles in males, which lie between the bladder and the prostate; notice their appearance and location as you practice on normals. Free intraperitoneal fluid, unlike fluid within organs, tends to form collections with sharp edges, or triangles, as it settles between structure, rather than rounded edges as seen within a viscus. Free fluid will also change size with patient repositioning and accumulation or drainage of fluid from that space.

Pericardial View

In patients with penetrating trauma who are in extremis, you should do this view first, since hemopericardium would prompt you to perform emergent thoracotomy or sternotomy. The pericardium can be viewed using either the *subcostal* or *transthoracic* views. If the patient can tolerate it, the subcostal view is performed by placing the probe in the subxyphoid space with the beam directed at the left shoulder and the probe indicator towards the patient's right shoulder. For morbidly obese patients or those with significant abdominal pain or upper abdominal injury, try the transthoracic view. The parasternal long axis view of the heart is obtained by placing the probe at the left fourth to fifth intercostals space just left of the sternum(*see* Fig. 6.8). Point the transducer indicator to the patient's right shoulder (10 o'clock) and manipulate it until all four chambers of the heart are seen. Pericardial blood shows up as a black stripe between the myocardium and the hyperechoic pericardium (*see* Fig. 6.9) Pericardial fat can show up as a dark stripe

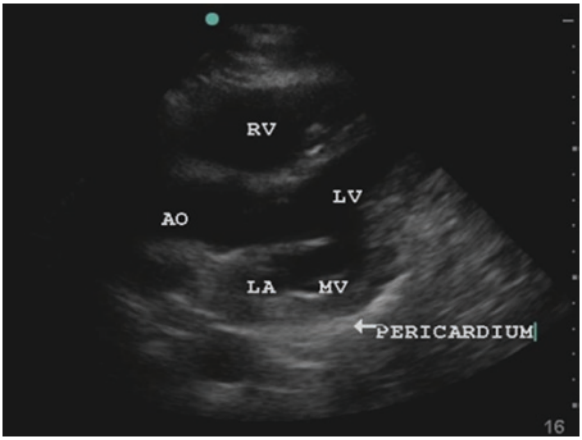

Fig. 6.8 Normal parasternal long axis view of heart. *RV* right ventricle, *AO* aorta, *LV* left ventricle, *LA* left atrium, *MV* mitral valve

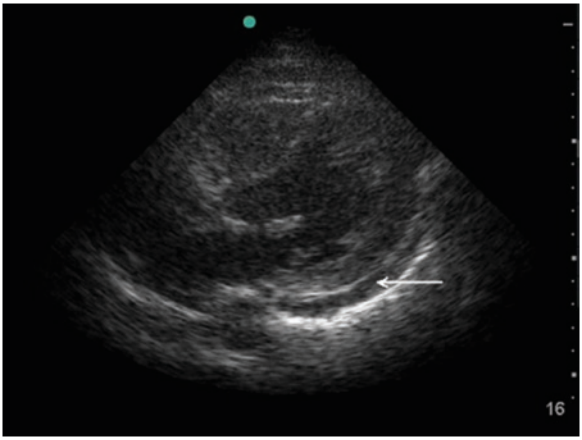

Fig. 6.9 Parasternal long axis view of the heart with *dark stripe* of pericardial effusion (*arrow*)

anterior to the right ventricle, but doesn't surround the entire heart. Slow and fine hand movements can greatly improve your image, or move to a different interspace if you cannot obtain a good ultrasound window at that position.

Pneumothorax Scan

US is about twice as sensitive as supine CXR in evaluating for pneumothorax in the trauma patient, approaching 90–95% sensitivity and 100% NPV. Basically, you are looking for the normal pleural interface (parietal and visceral pleura) sliding across each other. This pleural line is just deep to the rib shadows and is seen as a white, or hyperechoic line (*see* Fig. 6.10). When air is present between this interface, as in a pneumothorax, the normal "*lung sliding*" is absent. This sliding can be evaluated using color power Doppler (CPD) or M-mode; however, neither is necessary if you can see normal sliding. Another normal finding is "*comet tail*" *artifact*, which are white projections that are caused when US waves hit the normal pleural interface. These "rays" project down to the lower edge of the screen and are not seen if air is present. CPD, M-mode and comet tails all require motionless patients and therefore are of marginal utility in the austere environment (e.g. in a Humvee, FLA, Blackhawk or if the patient can't hold still).

The higher frequency (5–10 MHz) transducers show shallow anatomy best and conform nicely to the chest in most patients and should be used to evaluate for pneumothorax. In the supine patient air should collect anteriorly, so place the probe at the mid-clavicular space, identify the ribs first as landmarks for appropriate depth, then identify the pleural line just deep to the ribs and look for normal lung

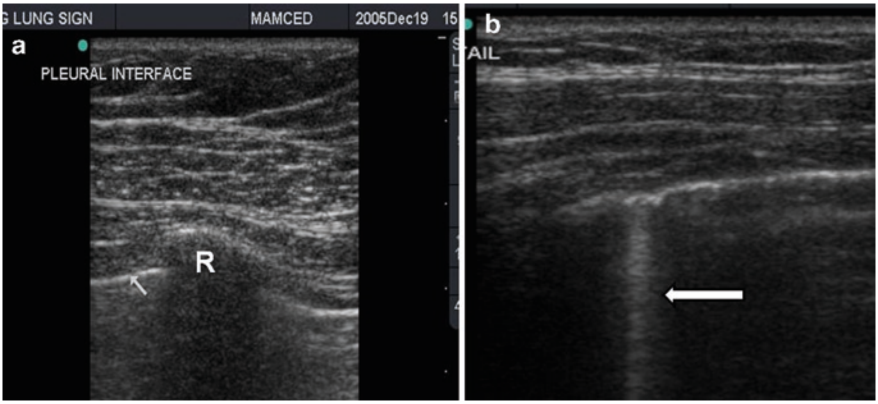

Fig. 6.10 Ultrasound evaluation for pneumothorax performed on anterior chest wall in mid-clavicular line. (**a**) The hyperechoic pleural line (*arrow*) is identified on the deep surface of the rib (R) which demonstrates posterior shadowing. Visible sliding pleural motion on real-time exam of this area rules out a pneumothorax. (**b**) Another finding of a negative examination is a comet tail artifact (*arrow*)

sliding. Repeat this two to three times in different anterior, sagittal planes for each hemithorax, sliding caudal over the anterior chest to the costal margins for each scanning plane. Pause between each interspace to confirm sliding, then as soon as you seen normal sliding, move on. This should only take less than a minute per hemithorax as long as you are sure there is normal sliding. For patients with hemodynamic instability or high suspicion (penetrating shrapnel wounds, crepitus, etc…), place a tube thoracostomy if no sliding is seen. Occasionally, patients arriving to our CSH had needle thoracostomies placed in the field but had normal underlying lung sliding on US, indicating no pneumothorax (later confirmed with CT) and thus obviating the need for immediate (or any) chest tubes. False positive findings may be seen with: (1) mainstem bronchus intubations (no sliding on opposite, normal lung) (2) Patients with previous underlying lung disease with adhered pleura/scarring (usually older, civilian casualties) and (3) normal lack of sliding near the pericardial-pleural interface on the left.

Making Clinical Decisions with EFAST Findings

In combat, US findings are acted upon primarily based on the type of injury, clinical stability and the operating environment available. Patients with hemodynamic instability and clear indications for surgery should be taken emergently to the OR without significant delay for imaging. In penetrating injury, perform EFAST when immediate surgery isn't clearly indicated, especially if multiple penetrating wounds are present, or high velocity GSW may have traversed multiple body cavities. US may help to prioritize surgical interventions such as pericardiotomy, thoracotomy, laparotomy or sternotomy. In patients going for emergent/urgent laparotomy, US can quickly rule out pericardial blood or pneumo/hemothorax enroute to or in the OR. EFAST findings can prioritize patients for evacuation and in mass casualty settings as well. In stable patients with blunt trauma, CT (if available) is a reasonable choice for an EFAST that shows intraperitoneal blood if nonoperative management is being considered. CT should always be performed for an equivocal/indeterminate FAST exam if available. If not, then close observation with serial exams or a diagnostic peritoneal lavage (DPL) can be performed. In the unstable patient with an equivocal or indeterminate FAST exam, you can quickly rule out abdominal hemorrhage as the source by performing a diagnostic peritoneal aspirate (DPA). Using either a standard DPL catheter or simply a syringe with an 18 gauge needle, aspirate as you penetrate the peritoneum (pelvis and/or paracolic gutters) with the needle. Any return of gross blood is positive and should prompt a laparotomy. See Chap. 5 for more on operative decision making, but try to do a quick EFAST if time allows in even the most critical patients, since you can quickly get a lot of useful information that may guide the sequencing of initial surgical resuscitation.

Other Useful Applications

Evaluation of Hemodynamic Status/CVP Measurement

US has additional utility in evaluating the patient in undifferentiated shock, looking for causes such as cardiac contusion/infarction, hemorrhagic shock, sepsis, pulmonary embolus and cardiac tamponade. While specific echo findings are outside the scope of this chapter, these are skills that can easily be picked up with some "off the cuff" training by the intensivists, emergency physicians and trauma trained surgeons with whom you deploy. To estimate the CVP in any of these scenarios utilizing US, place the low frequency probe in the sagittal plane (probe held longitudinally, marker cephalad) in the subxiphoid region to see the right atrial-vena caval junction (*see* Fig. 6.11). The IVC immediately adjacent to the right atrium (RA) responds directly to the pressure of the right atrium and is a rough estimate of RA pressure. CVP *estimate* may be made based on the IVC size (normally 1.5–2.5 cm diameter) and response to inspiration in the following manner:

(a) Total or significant IVC collapse at inspiration → Low RA pressure patient needs volume resuscitation and/or hemorrhage control
(b) Normal sized IVC and moderate collapse (less than 50%) → Normal RA pressure
(c) Large sized IVC and little or no IVC collapse → High RA pressure volume overload, cardiac tamponade, heart failure

IVC estimation can be a helpful adjunct, but it should not be used as a sole deciding factor early in the resuscitation. Make initial management decisions based on the

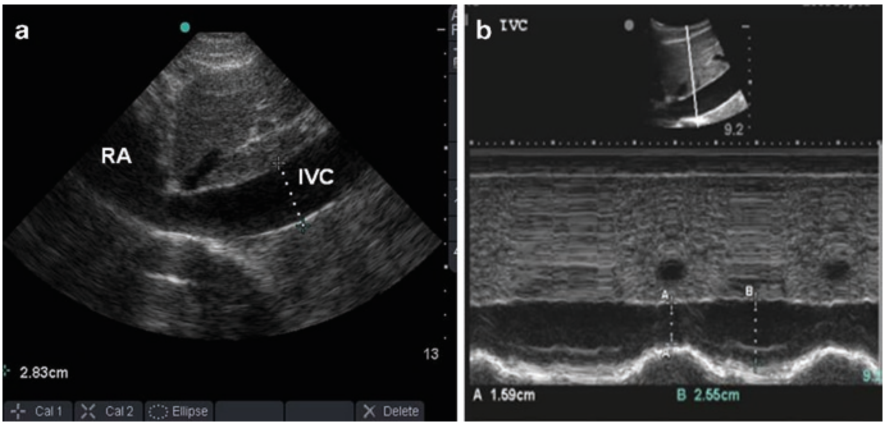

Fig. 6.11 Ultrasound evaluation of the inferior vena cava for volume assessment. (**a**) The vena cava (IVC) is demonstrated as it enters the right atrium (RA) in longitudinal section and the measurement of 2.8 cm suggests adequate intravascular volume. (**b**) M-mode evaluation of the vena cava is used to compare the diameter at inspiration (**a**) to that at expiration (**b**). Note that this vessel shows less than 50% collapse, again indicating adequate intravascular volume status

patient's hemodynamic stability, history and clinical evaluation of injuries. IVC estimation may certainly be useful later in the postoperative phase, as when receiving patients from a FST after damage controlled resuscitation or other "used" civilian and military trauma victims. This is very subjective measurement that also requires you to see many normal studies to recognize when abnormal.

Triage

Mass casualty scenarios are always a possibility on today's battlefield. Most commonly, "Mini-Mass-Casualty" scenarios are encountered when explosive devices injure several or more patients that you are called to assess. US can be an invaluable tool in gaining a lot of useful information in a short amount of time. If the surgeons and emergency physicians are busy leading the resuscitations, other trained team members can serve in this role. Radiologists, OBGYN doctors, nurses and even combat medics can be trained to perform EFAST when your trauma team and usual sonographers are tied up.

Procedural

Central line placement under US guidance is becoming the standard because data suggest there are fewer complications than when doing them blind. If time allows in the stable patient, this is a great time to refine this skill as well. Other common procedures such as thoracentesis, paracentesis, percutaneous abscess drainage, and pericardiocentesis are greatly enhanced by the addition of ultrasound guidance.

Foreign Body/Soft Tissue/Musculoskeletal Application

You may be assigned to a FST working outside of a CSH, or in some other scenario where you do not have radiographic or CT support. US can be very useful in identifying soft tissue foreign bodies, differentiating cellulitis from abscess, and evaluating other soft tissue injuries and infections. With practice, you can assess for long bone fractures and dislocations without plain x-rays in even the most austere settings.

Other

While outside the scope of this chapter, other relatively easy scans that may be performed in the austere setting include: gallbladder (stone/infection), hydronephrosis from kidney stone, AAA and pregnancy scanning for IUP vs. ectopic. Many other applications, such as retinal detachment or ocular foreign bodies, compression studies of the lower extremity venous system for DVT and testicular ultrasound are easily performed with the basic US system that most units deploy with to OIF/OEF.

In conclusion, the utility and applications of ultrasound technology in combat trauma have been solidly established and continue to rapidly expand. The flexibility, portability, and ease of use of modern ultrasound platforms make this an ideal imaging modality which is becoming a standard adjunct to the physical examination. Your investment of time in developing a solid foundation of ultrasound skills will pay great dividends in any forward deployed or disaster scenario you may be faced with.

Chapter 7
The Bowel: Contamination, Colostomies, and Combat Surgery

Eric K. Johnson and Scott R. Steele

Deployment Experience:

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	Task Force Surgeon, US Special Operations Command, Afghanistan, OEF 2007, Iraq, OIF, 2008
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	745th Forward Surgical Team, Amarah, Iraq 2008

BLUF Box (Bottom Line Up Front)

1. Control of contamination from gastrointestinal tract injuries is a priority during damage control, but hemorrhage control comes first.
2. Combat wounds are different than any civilian trauma – and should be treated that way.
3. Damage control bowel surgery means staple off or whip-stitch closed. In the unstable trauma patient, control hemorrhage, control contamination, and *get out of dodge!*
4. High velocity injuries and multiple small fragments can result in injured bowel that looks okay – have a low threshold for a planned second look operation.
5. Missed injuries kill. Pay special attention to the posterior stomach, duodenum and jejunum near the ligament of Trietz, and base of the mesentery for vascular rents.
6. The debate about colostomy versus primary anastomosis rages on, but in combat injuries you should divert much more liberally; particularly in the presence of multiple abdominal injuries.

If you do a colostomy there will be someone to tell you why not primary anastomosis; if you do a primary anastomosis there will be someone to tell you why not colostomy.

Mosche Schein

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Traumatic bowel injury in the combat casualty is extremely common and you must be comfortable with its management. Luckily, despite all that is written, the basic principles that govern the operative management for traumatic bowel injury boil down to control of hemorrhage and contamination, assessment of bowel viability, determination of need to resect *vs*. repair, and choice of reconstruction. Combat casualties tend to present with a multitude of injuries from combined mechanisms, so they must often be managed through means not typical of civilian trauma surgery. This is not the setting or the patient population to "try out" some great new technique you just read about or to push the envelope of primary reconstruction. While there are many ways to "skin a cat", we will present you with some techniques and advice that we found useful in the management of these complex injuries.

Does the Patient Have a GI Tract Injury?

The answer to this question is often obtained in the operating room, although in the modern combat support hospital you will usually have access to a CT scanner and may know the answer ahead of time. The bigger issue to address remains: does this patient need to go to the operating room? A combat casualty that presents with a penetrating mechanism and a wound that violates the peritoneal cavity requires abdominal exploration; Period. Hemodynamic stability may buy you time to better evaluate the situation with adjunctive studies. Yet, the bottom line for the *unstable* patient with a suspicion of intra-abdominal trauma based on injury pattern and mechanism remains that if the pattern and mechanism point to the abdomen, then a laparotomy is in order. You will figure out what is damaged in the operating room, and preoperative imaging will add little benefit. In fact, "stable" is often really a misnomer for the combat casualty with a penetrating wound to the abdomen. They may appear clinically well for the moment, but that can change quickly. Unfortunately, you will likely encounter a situation where a patient with a penetrating abdominal wound has to wait in line for the operating room either from a mass casualty event or expended resources. Don't forget this patient – assign a nurse or medic to re-evaluate him frequently in your absence, as they may push themselves to the "front of the line".

Trust your physical exam and clinical judgment, you will rarely regret it. If the patient is awake and alert, then do a careful physical exam of the abdomen. In these mostly young and healthy patients, the abdominal exam is highly reliable for identifying peritonitis. If you push on their belly in two separate places and they have a clear severe pain reaction – that is peritonitis. No CT scan is needed to "confirm" your exam or to look for other abdominal injuries. Your careful exploration should be better than any CT scan. If they are not examinable, then you have to rely on injury patterns and possible imaging studies but should have a low threshold for exploration.

What to Do Once in the Operating Room?

Make a big enough midline incision so that you may adequately explore all quadrants of the peritoneal cavity. You will likely encounter lots of blood and contamination and perhaps a large retroperitoneal hematoma, but don't let this affect you. Have a systematic approach to packing the abdomen and exploring it one area at a time. Control hemorrhage first and then spend time controlling contamination. Many of these casualties will require a "damage control" approach to treatment. We found it useful to have an egg timer in the room that was set for 45 min. When that timer went off, we knew it was time to start "cleaning up" and ready the patient for transport to the ICU. You want to be fast, but not furious. Calm and focused gets you out of the OR faster and safer than panicked and hurried. Don't get in such a hurry that you miss a major injury that will lead to the patient's demise. A small missed injury may be forgivable when you go back later and find it, but a major missed injury is a mistake that may not give you another chance.

We employ two useful techniques to quickly control contamination from bowel injuries. In the umbilical tape approach, mesenteric windows are created on the proximal and distal sides of the injury, which the tape is then passed through and tied (Fig. 7.1). This works well when you have focal areas of injury, but is not as effective when you have a long segment of injured small bowel or colon that is laden with succus or stool. The second approach requires the use of gastrointestinal anastomotic stapling devices. In this approach we rapidly create mesenteric windows on both sides of the injury and then fire the staplers through the windows effectively closing and dividing the bowel at these points. We then fire additional staplers across the mesentery of the injured bowel, staying close to the bowel wall and using vascular loads. You can resect injured segments of small bowel in less than 60 s using this technique. Alternatively you can take the mesentery with the

Fig. 7.1 Rapid control of bowel contamination using umbilical tapes passed through a small mesenteric window and tied to occlude the lumen

serial creation of windows and placement of clamps. To make this maneuver faster, take large bites of the mesentery with each clamp (3–4 cm) for en masse ligation and only clamp the proximal side. Use your hand to control bleeding from the distal side until the specimen is excised.

Colonic resection in mobile areas can be accomplished almost as quickly with the same techniques. Injuries to the colon at points of retroperitoneal fixation such as the ascending and descending colon simply require a moderate amount of mobilization to achieve the same end. You can also employ the use of atraumatic bowel clamps to assist when there are multiple areas of contamination to deal with, or to close small anterior holes. In the "damage control" setting, this is all that is initially required. A quick washout and temporary abdominal closure is all that remains between the patient and critical care in the ICU. *Do not* get bogged down by small bleeders in this situation. Just focus on getting your cold, coagulopathic, and acidemic casualty to the ICU where these problems can more effectively be addressed.

Injuries to the Stomach

You must expose the entire stomach and use both inspection and palpation to evaluate for injuries. Your high risk areas for a missed injury are high at the gastroesophageal junction or along the lesser curve. If there is a hole in the stomach then always find the other hole or explore it well enough to convince yourself 100% that there isn't another one. Retract the left lobe of the liver anteriorly and open the avascular gastrohepatic ligament to examine the lesser curve. The lesser sac should *always* be opened and inspected, which allows evaluation of both the pancreas and the posterior stomach. Divide several inches of the gastrocolic ligament along the greater curve at the midpoint to enter the lesser scar. Retract the greater curve anteriorly and to the right to examine the posterior stomach, and insert your entire hand into the lesser sac to palpate for injuries. Squeeze the stomach or insufflate with air via the nasogastric tube to look for extravasation of fluid or food particles.

Most nondestructive injuries to the body of the stomach can be managed through simple mobilization of the organ and closure of the hole with a single firing of a TA or GIA stapler. Injuries involving the lesser and greater curvatures of the stomach may be addressed by a wedge resection of the injury using two firings of a gastrointestinal anastomotic stapling device. The stomach possesses a tremendous amount of redundancy, which is to the surgeon's advantage. Destructive injuries to the greater curvature may be managed using a sleeve gastrectomy technique as long as a reasonable lumen is preserved (Fig. 7.2). The patient may lose some weight in the long run, but they will be alive.

Severe injuries to the antrum may require antrectomy and reconstruction. Our advice here is to keep the procedure simple and complete. Beware of leaving retained antrum on the duodenal side of the resection if you plan on using loop or Roux-en-Y reconstructions. Take only what you need to take since the indication for resection is trauma. Our preferred reconstruction is a gastrojejunostomy with

Fig. 7.2 Resection of part or all of the greater curve is accomplished rapidly with a stapled sleeve gastrectomy. Ensure you leave at least 3–5 cm of antrum to avoid dysmotility and obstruction problems (modified with permission from Smith et al., Endocrinology and Metabolism Clinics of North America 2008;37:943–964)

Braun entero-enterostomy because of its simplicity. Utilize GIA staplers as much as you can, but sutured anastomoses can be quite useful in the setting of edematous bowel and where staplers are not available. Injuries to the gastro-esophageal junction can be quite complex and difficult to treat. Utilize a gastro-esophageal anastomosis only when absolutely necessary as this anastomosis can be difficult to construct and comes with a high risk of leak. The circular stapling device can simplify this problem, but nondestructive injuries are probably best managed with primary closure (over a bougie dilator), nasogastric decompression, and closed suction drainage. Assess any potential damage to the vagus nerves that may require you to perform a pyloroplasty, although this is rarely needed. Don't waste time on steps like this in the damage control setting. You do not need to leave drains at the initial damage control procedure if you have adequate closure of the defect and are planning a vacuum type temporary closure and second look operation. A closed suction drain should be left adjacent to your repair prior to fascial closure or at your last exploration prior to placing the patient in the evacuation chain.

Injuries to the Small Intestine

You have done a damage control laparotomy on a soldier who was injured when a roadside bomb detonated under his vehicle. He had about 100 small fragment wounds to his torso and bilateral amputations. You "ran the bowel" in standard fashion and fixed several mesenteric tears before your temporary closure.

He is now febrile to 103F and oliguric in the ICU. When you re-open his abdomen in the OR you find enteric contents throughout the belly from several pinhole sized enterotomies. Don't let this scenario happen to you or your patient. The number one principle for managing small intestine injuries is *find all the holes*. This is easy with a high velocity gunshot wound that blew apart the terminal ileum, but can be extremely difficult with multiple millimeter-sized fragment wounds. This mechanism is not seen in civilian trauma, where the rapid hand-over-hand running of the bowel is fine to rule out bullet sized holes.

For these types of combat injuries you must identify the obvious injuries, and then diligently search for the less obvious ones. Pinhole sized enterotomies from fragment wounds may look like a speck on the serosal surface or a tiny hematoma that you would otherwise leave alone. The other common area for missed injury is a perforation into the mesenteric border, which may look like a small mesenteric hematoma or discoloration at the bowel margin. Firmly grasp and elevate the bowel as you run it. Milk each segment manually to observe for spillage or leakage of air. Even though you may be in damage control mode, take the 5 min to slowly and carefully run the entire small bowel. Explore any area of question on the serosal surface or at the mesenteric border. If you are still not sure if there is an injury, you can insufflate air or saline via a 20-gauge needle into that segment of bowel while occluding proximally and distally. Oversew any areas of concern as you proceed along the bowel. When you identify an injury or serosal tear that requires repair, do not proceed with a plan to come back and fix it after running the rest of the bowel. Either repair it right away, or mark it with a suture to repair later. In the heat of battle there are many distractions that could result in you forgetting about the injury, with disastrous consequences.

These injuries are the simplest to manage from the technical aspect, but there are a few pitfalls with which to be familiar. The primary goal of trauma surgery is to save the life of the casualty, but you must also consider the long-term consequences of the procedure you perform. You must try to preserve small bowel length, but you cannot do this at the expense of the patient. If it needs to be resected, than you must resect it and deal with the consequences later. The first step once you have identified the injuries is to classify them in your mind as "destructive" or "non-destructive", which will determine your repair options. In general, destructive injuries involve 50% or more of the circumference or have disrupted the mesenteric blood supply enough to result in ischemia (Fig. 7.3). These injuries should prompt resection. Other indications for bowel resection are multiple closely clustered injuries to a focal segment, a large complete mesenteric defect ("bucket-handle" deformity, Fig. 7.4), or failure of a prior primary repair.

If the injuries are amenable to primary repair, then proceed with a definitive repair technique. You should debride the injury margin sharply to viable, bleeding edges, and then repair them in a transverse fashion such that the bowel lumen is not narrowed. Look for a white discoloration of the serosa surrounding larger fragment holes – this is a thermal burn and must be entirely excised prior to repair (Fig. 7.5). Primary repair can be done with suture or TA staplers but remember that the stapled

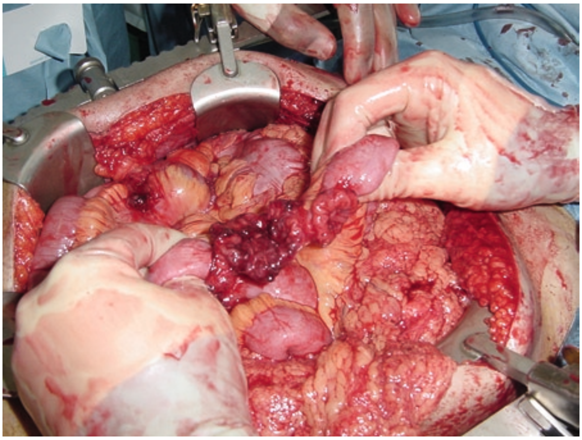

Fig. 7.3 Multiple destructive bowel injuries from a high velocity gunshot wound

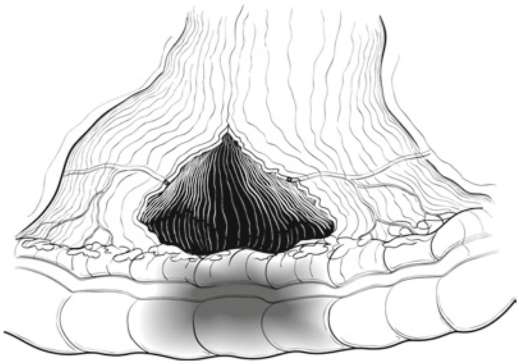

Fig. 7.4 Mesenteric injury ("bucket handle" deformity) with intact bowel wall. This injury should prompt resection

method will almost always result in more narrowing than a sutured repair. Injuries that are not amenable to primary repair should be resected and ultimately re-anastomosed using a side-to-side technique that can be performed with linear staplers or sutures. Sutured anastomosis may be more secure when confronted with severely edematous bowel, but otherwise it is based on surgeon preference and the importance of speed (stapled is always faster). A rapid technique for performing the stapled anastomosis and resection at the same time using only two stapler firings is shown in Fig. 7.6. If you are resecting a very large segment, or multiple segments, remember to measure and record the amount of small intestine that remains intact. A *minimum* of 100 cm of small bowel in the absence of the ileocecal valve or 75 cm with an intact ileocecal valve is preferred to maintain adequate nutrition via the enteral route. It is also ideal to preserve as much of the terminal ileum as possible since it has specific functions that are not present in the jejunum.

Fig. 7.5 Bowel injury from a blast fragment demonstrating small enterotomy and larger surrounding area of thermal injury (*white tissue*). The entire thermal injury must be debrided

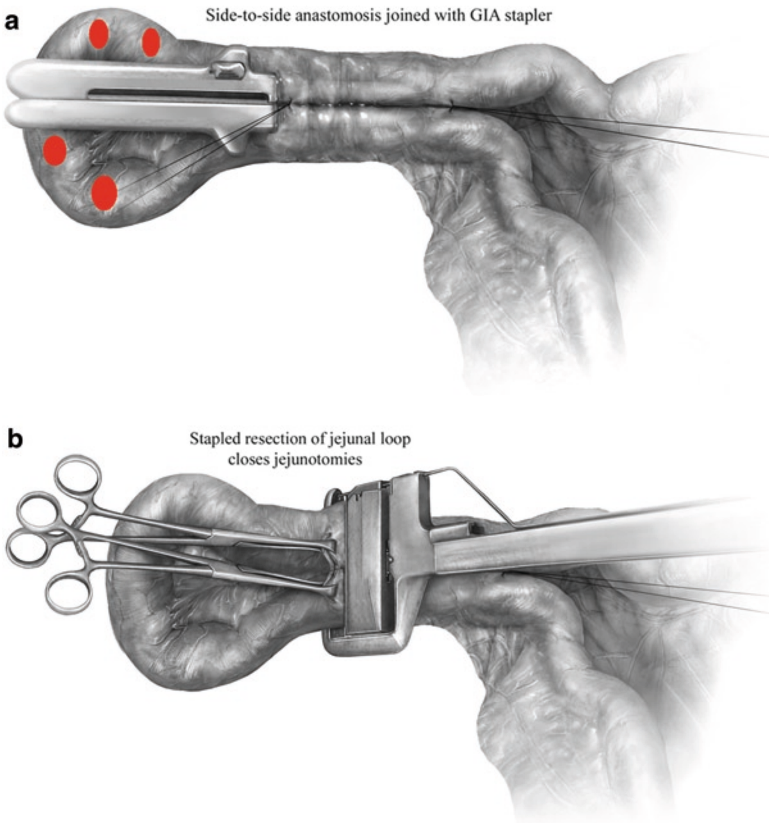

Fig. 7.6 Double-stapled technique for simultaneous resection and bowel anastomosis. The bowel proximal and distal to the injured segment (*circles*) is opposed and an anastomosis is created with a linear stapler (**a**). The resection is then completed by firing a linear stapler transversely, incorporating the two limbs of the injured segment and the common enterotomy for the anastomosis (**b**). (Modified with permission from Martel et al., Operative Techniques in General Surgery 2007;4:13–18)

Another issue we often face is whether or not to preserve the ileocecal valve. Obviously its preservation is preferred, but when the integrity of this portion of the intestine is in question, then it should just be resected in the combat casualty. If bowel looks marginal at the first laparotomy, it will look worse at the next. High velocity missiles do a tremendous amount of collateral damage, and you will often be forced to remove more intestine than you would in the civilian trauma setting. Preserve the structure if you can, but place an anastomosis no closer than 5 cm proximal to the valve to avoid constructing an anastomosis at the site of a potential distal obstruction. If the valve itself is injured, we would not recommend trying to repair it. Perform an ileocecetomy and an anastomosis or a diverting ileostomy as clinically indicated.

Injuries to the Colon

Colonic injuries are common and are associated with higher rates of infection and postoperative complications than other GI tract injuries. You will certainly encounter colonic injuries that are tempting to repair primarily. *This is not civilian trauma!* Forget what you learned by reading the recommendations for the treatment of penetrating colonic injuries in civilian trauma patients. We recommend resection of penetrating colonic injuries caused by high velocity missiles in all but the smallest of injuries – and even then consider resection. You do not need to perform the typical oncologic procedures, but you should resect the injury with a significant margin of normal appearing bowel. Ensure that the remaining bowel has a good blood supply via the ileocolic, middle colic, inferior mesenteric, or marginal arteries through collateralization. One common scenario that is encountered is injury to one of the main vessels supplying the colon. When this occurs, you must assess the viability of the effected region of the colon. If there is any question, then it should be resected. The marginal artery will keep just about any portion of the colon alive as long as it is preserved. Always consider the watershed areas of the colon (splenic flexure and sigmoid) carefully when confronted with this situation.

You will inevitably encounter the situation where a projectile penetrates the mesentery adjacent to the colon, but does not result in a colostomy. Take caution in this situation. Often the result is injury to a portion of the marginal artery and cavitation effect on the bowel wall (Fig. 7.4). The colon will appear viable but may not remain so after your procedure is complete. This is where combat surgical judgment is paramount. Our recommendation is to perform a segmental resection in this situation with an anastomosis if clinically indicated. Ileocolonic and colorectal anastomoses are the easiest to construct and are the most reliable.

Mandatory colostomy for all combat-related colon injuries was historically practiced by the military based upon the dismal outcomes with early attempts at primary repair or anastomoses. As with most "mandatory" dictums in surgery, this practice is not supported by current data or experience from both combat and civilian trauma but still has some supporters. On the other side of the argument, the current civilian practice has moved toward primary anastomosis for almost all penetrating colon injuries. The "truth" for combat colon injuries lies somewhere in the middle of these positions, but we clearly should be more conservative than our civilian counterparts with attempting primary anastomosis. The decision to perform an anastomosis is often a difficult one and is based on good clinical judgment and an assessment of the tactical situation. You have to take into account the portion of colon injured, the stability of the patient, the level of contamination, the mechanism of injury, and the presence of associated injuries. You should also consider whether you are going to be able to observe the patient closely postoperatively, or whether you will be placing him into the medical evacuation chain. Right-sided injuries may often be re-anastomosed in patients that are hemodynamically stable, non-coagulopathic, warm, and non-acidotic. Anastomosis in the setting of massive transfusion, multiple colonic injuries or associated injuries such as a pancreatic injury *should not* be performed. These patients are better served with ileostomies or colostomies, or a damage control procedure with the bowel initially left in discontinuity and re-examined following resuscitation. Perform a tactical retreat and return to fight another day.

In general, there remains a lot of debate regarding the use of stomas or primary anastomoses for left-sided injuries. As above, there are certain situations where it is clear that you should bring up an ostomy (i.e., massive transfusion, multiple injuries, etc). For the remainder of the injuries, you should evaluate them on an individual case based on other factors. If there is any doubt, left-sided injuries should not undergo re-anastomosis in the setting of combat trauma. You may “get away” with this once, but you will live to regret it if you make this a matter of practice. There will be many situations where only a small amount of colon requires resection and the easiest method of reconstruction is to perform a colo-colostomy. Also, do not forget about the option to perform a primary anastomosis and use a proximal stoma (i.e., loop ileostomy), as this can divert the stool while distal healing takes place. Figure 7.7 demonstrates an easy technique to perform a completely diverting and easily reversible “end-loop” ostomy. Remember that the anastomosis may still leak, but proximal diversion minimizes the resulting clinical sepsis. This also makes the subsequent operation for ostomy reversal a much easier and lower risk procedure. Hand-sewn or stapled techniques both work well, but we recommend you follow the same rules stated above for creating an anastomosis.

It is also important to keep in mind the differences in culture and support when dealing with the local national population with colon injuries. Stomas are viewed in different, and often untoward, ways in many societies. As such, patients are commonly faced with limited supplies, technical and emotional support, and may be viewed as outcasts within their own population. They can also be expected to have little to no access to high quality medical or surgical care in the future, and may never have the chance for ostomy reversal. While this may cause you as a surgeon to be more apt to perform a primary anastomosis, this must be weighed against the increased risks of concomitant underlying malnutrition, co-morbidities, tobacco use, and limited medical support should the patient leak. Helping your situation, many local nationals will be able to stay under your care for longer periods of observation than coalition troops undergoing medical evacuation within

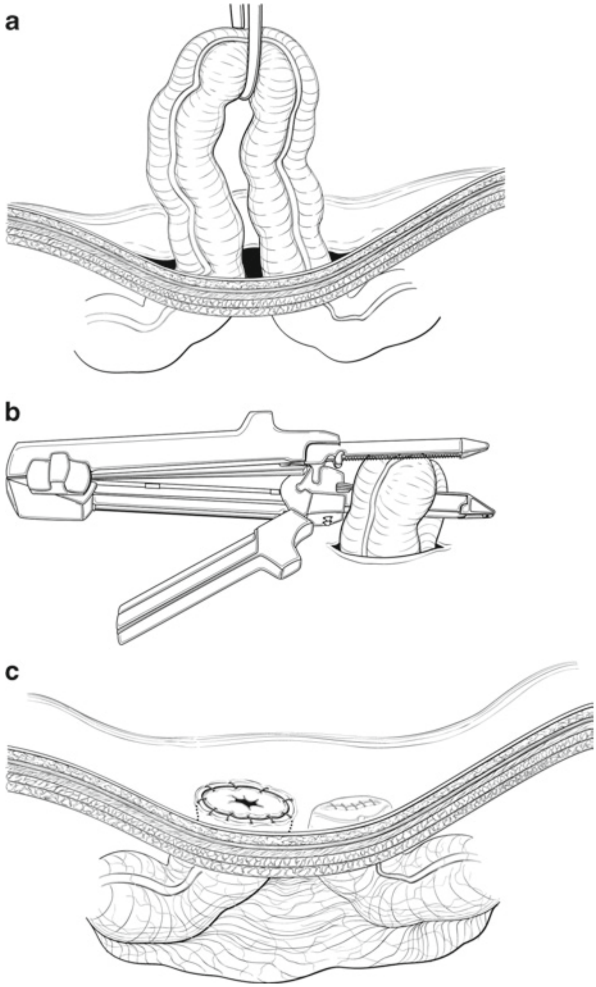

Fig. 7.7 Technique for a stapled "end-loop" ostomy. The ostomy loop is delivered through the fascial defect (**a**) and divided with a linear stapler (**b**). The proximal staple line is excised and the ostomy matured to the skin, while the distal stapled end is left in the subcutaneous position for easy subsequent closure (**c**)

24–36 h. Based on this very different risk/benefit analysis (compared to U.S. soldiers or civilians), many deployed surgeons have thus adopted a more liberal policy for doing primary anastomoses in local national casualties. Although these considerations are rarely discussed, and may be even more difficult to grasp, you need to take these into account when encountering this injury pattern in the local population.

Injuries to the Rectum

In general, diagnosing and localizing rectal injuries can often be difficult but addressing rectal injuries should be fairly straightforward. The basic principles of proximal diversion and distal washout will work in most situations. Presacral drainage has been debated over and over, but we feel that it is not necessary in the majority of cases. Perhaps the only case is for a large sacral injury with a lot of spillage, and then for only a short time initially to evacuate the fluid. The real challenge with these injuries can be their identification. A patient that presents with a suspicious pattern of wounding (penetrating gluteal, trans-pelvic wound, multiple perineal fragments) or hematochezia should undergo rigid proctoscopy to identify an injury. A patient with blood in the rectum on proctoscopic exam without an identifiable proximal source has a rectal injury until proven otherwise and should be treated as such. For those patients undergoing preoperative CT scans, look for perirectal edema or stranding, pelvic fragments, and air or fluid in the pararectal space, all of which may indicate rectal injury. As such, these casualties should be approached as if they have a rectal injury. Rectal injuries are managed differently depending on whether the injury is intra- or extraperitoneal. Intraperitoneal rectal injuries can be managed in the same manner as left-sided colonic injuries. The injury should be resected leaving a Hartmann's pouch distally and a colostomy can easily be created from the proximal sigmoid colon. In select situations (rare in combat) you can consider a colorectal anastomosis, but we would recommend strong consideration of a proximal diverting loop ileostomy if this option is chosen.

Extraperitoneal injuries present a different challenge. The simplest and most straightforward method of managing these injuries is to create an end-loop colostomy (Fig. 7.7) and perform a distal rectal washout. A loop of sigmoid colon is chosen for colostomy formation and is delivered onto the anterior abdominal wall through a properly sited stoma aperture. Flow into the efferent limb of the stoma is prevented by stapling across the distal portion with a transverse firing of a TA-60 stapler. Prior to the firing of this stapler, a large bore catheter is placed into the afferent limb of the stoma and saline is flushed through while an assistant keeps the anal sphincter open to prevent any resistance to flow (often with the use of a rigid proctoscope). This cleans out the distal rectum and makes presacral drainage unnecessary. Ventilator tubing borrowed from anesthesia can be placed into the open bowel and secured with an umbilical tape to perform an on-table lavage (Fig. 7.8). The TA-60 stapler is then fired and the colostomy is matured. Pre-sacral drainage is talked about more often than done. The problem with presacral drainage is that you have to enter the presacral space from a perineal approach and you have to dissect into the area of injury. The drain must be placed in this area to be effective. Because of the difficulty with this approach, the drain is often malpositioned and ineffective. There is no need to expose and resect extraperitoneal injuries. They will typically heal after a period of diversion, and those that don't can be approached in the elective situation. Whatever you do, do not spend any amount of additional time trying to identify and repair an extraperitoneal rectal injury that will do just as well with diversion alone. This will only lead to

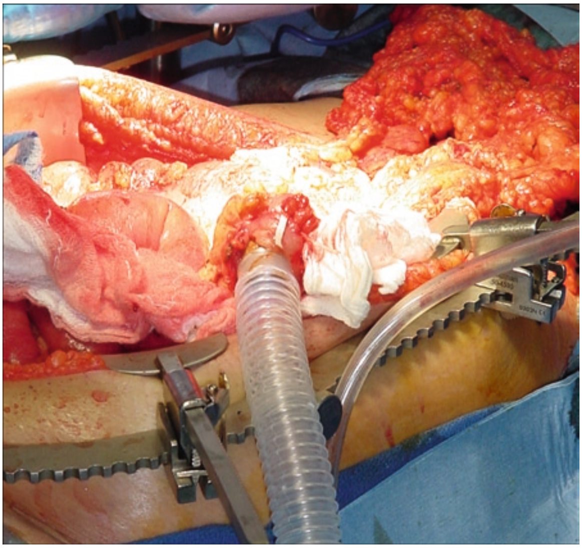

Fig. 7.8 Simple technique for on-table bowel lavage using ventilator tubing (disposable ventilator circuit set) secured in the bowel lumen with an umbilical tape

prolonged operative times, increased blood loss, and onset of the lethal triad of acidosis, hypothermia and coagulopathy, if it is not already present.

You may encounter the scenario where the casualty has a destructive rectal injury associated with pelvic hemorrhage or a massive perineal wound. This is more complex and will usually require some extraperitoneal resection and pelvic packing to control hemorrhage. Most often the exposure has been performed for you by the missile or fragment that caused the injury. The best move in this situation is to pack the pelvis with laparotomy pads to control hemorrhage and attempt to control contamination to the best of your ability. This will almost always be a patient who undergoes a damage control procedure with a stay in the ICU for rewarming and resuscitation. Once the patient has been stabilized and has met your criteria for resuscitation, you may return to the OR and “clean” up. This will often require resection of devitalized extraperitoneal rectum and maturation of a colostomy. The patient is often left with a very short Hartmann’s pouch in this setting. Pelvic exposure is often difficult to obtain and can be improved through the use of a simple technique that we advocate. We use a Bookwalter or similar self-retaining retractor system to assist with retraction of the midline incision. The bowel can then be wrapped in a moist towel and packed cephalad. A handheld large malleable retractor is then bent into a U or horseshoe shape and placed at the pelvic inlet. This works very nicely to keep the pelvic inlet widely exposed and prevents the bowel from “creeping” into the operative field. This will provide adequate pelvic exposure for any possible scenario, and is particularly useful if you are operating without the assistance of a second surgeon to aid exposure.

Finally, we recommend a colostomy in those patients with a large perineal injury that disrupts the anal sphincter causing continence disturbances. Also, those patients with complex pelvic fractures, spinal cord injuries, and open pelvic and perineal wounds in which fecal soilage may lead to an increased risk of infection and difficulty with wound care, all should undergo stomal placement.

Timing of Reconstruction After Damage Control

This is a subject that can be debated vigorously. We think that it should be summarized in two questions: when do you go back to restore small bowel continuity, gastric continuity, and create stomas; and how do you decide whether or not to restore colonic continuity? Obviously the less time the patient spends with bowel ending blindly, the better. Damage control is performed to avoid a lengthy initial procedure in the operating room that the patient is too unstable to endure. These patients often either present with or develop hypothermia, coagulopathy, and acidosis. They are unstable and often require a massive transfusion of blood products. They are too sick to withstand the surgical insult, and any repair performed at the time of initial surgery is likely to fail. For this reason, our initial goals are simply to control hemorrhage and contamination and leave the operating room. The care provided in the ICU will eventually result in the correction of the lethal triad or the patient will expire. There is no pre-ordained time frame for the patient to return to the operating room. They are ready to return when they are no longer cold, coagulopathic, and acidemic. That may be in 8 h or it may be in 2 days. In general, we would prefer to go back to the operating room within 48 h, at least for a washout. Aggressive resuscitation will commonly facilitate this, often within the first 24 h. Yet, correction of the patient's physiologic milieu will be the determining factor.

When the patient does meet criteria to return to the OR, they may still not be in optimal shape for restoration of GI continuity. If the bowel is markedly edematous, it is probably not the optimal time to perform an anastomosis. If all that needs to be completed is a colostomy, than that can certainly be done the first time they return to the OR. Abdominal closure is often not possible, and must be delayed until appropriate. A temporary abdominal closure is employed until no longer necessary. It is probably not wise to leave multiple sections of blind small bowel and colon for much longer than 72 h. Once this time period is reached, you should consider beginning your reconstructive plan if you haven't already. Gastric and small bowel reconstructions are less fraught with complication and can be performed using staplers or sutured techniques even if the gut wall is edematous. The real judgment comes in to play with restoration of colonic continuity. As stated previously, we recommend diverting many left-sided resections. This may include the use of a primary colo-colostomy and diversion of the fecal stream proximally with use of a loop ileostomy. Restoration of right-sided resections can be performed if they are appropriate to perform soon after the first damage control procedure. If the patient has a prolonged resuscitation or the bowel remains very edematous after the first 72 h, we would recommend diversion with an ostomy and mucous fistula or long Hartmann's pouch.

"Used" Trauma

You may at some point receive patients who have undergone a laparotomy for bowel or other abdominal injuries at an outside facility. If this was a U.S. or coalition military medical unit, then you will usually receive adequate documents to sort out what was done. However, you will also receive patients who were treated at a local facility with vastly different practices, supply situation, and trauma capabilities compared to a modern U.S. facility. They will often arrive poorly resuscitated or in-extremis, and with either indecipherable medical records or no documentation whatsoever. Two local practices that were commonly encountered in the local management of abdominal injuries were: (1) to leave open colon wounds in-situ with a small drain placed adjacently and close the abdomen, and (2) to bring out the injured portion of bowel to the skin as a makeshift ostomy. You will also encounter patients who had a colostomy performed as a routine part of the trauma laparotomy, and who have no bowel injuries or true indication for diversion. It was not uncommon to re-explore the abdomen in these patients and find extensive dead bowel or ongoing soilage with resultant sepsis and/or death.

Treat these transfers like a fresh trauma and assume nothing! Start resuscitation, administer antibiotics, and prepare your operating room. Work them up from head to toe as if they had just been injured and not received any care or evaluation. All of these patients should undergo immediate exploratory laparotomy to sort out their anatomy, treatment of injuries, missed injuries, and extent of abdominal soilage. In many cases you will find an abdominal disaster brewing or in an advanced stage and should initiate a full damage control strategy. In other cases you may find no significant injuries and may even be able to perform immediate reversal of an inappropriately placed ostomy.

Tractotomies/Treatment of Entrance and Exit Wounds

Penetrating trauma resulting from high velocity missiles that injure the bowel often leads to infection. There is often considerable spillage of GI content and the exit wound, if present, is often severely contaminated with this material. You are not done when you finish addressing the gastrointestinal injury. You must address the wounds – particularly the exit wound. There is often considerable tissue destruction in the vicinity of the exit wound. When this is combined with GI contamination, a sort of "perfect storm" for infection occurs. The exit wound should be debrided to ensure removal of all devitalized tissue, along with extensive irrigation of the remaining wound, with pulse-lavage, if available. This wound should then be observed serially for signs of infection. Any high febrile episode or foul drainage from the wound should be re-evaluated in the operating room. Necrotizing soft tissue infections are not uncommon in this scenario and are best managed early and aggressively in their course.

Final Points

Just as any infantryman goes into battle with an assortment of weapons, ammunition, and techniques, you must go into the operating room armed for the various scenarios you may encounter. Don't make the mistake of treating combat casualties like you would victims of civilian trauma. The anastomosis that looks great when constructed will be leaking in 48–72 h and you will scratch your head and wonder why. They are just sicker patients. The mechanisms of injury are more severe and are often combined in additive or exponential fashion. It is not uncommon to see a patient that has a combination of blunt, blast, burn, and penetrating trauma. They will not react or heal like someone who was wounded with a 9 mm pistol or was in a car accident. There will be times when you can revert to the standard methods, but when confronted with a very injured and very unstable casualty, you have to think outside the box.

Chapter 8
Liver and Spleen Injury Management in Combat (Old School)

Brian Eastridge and Lorne Blackbourne

Deployment Experience:

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BLUF Box (Bottom Line Up Front)

1. Sometimes your clinical judgment is all you have.
2. Remember the clock started long before the patient got to you…prevent and treat the lethal triad.
3. Damage control resuscitation and damage control surgery…temporizing therapy saves lives.
4. Solid organ injury in the abdomen in combat is almost exclusively a surgical disease.
5. Keys to a successful operation: Exposure, Exposure, Exposure. Big problems require big incisions, and they heal side to side not end to end.
6. Spleen: if it is injured, it belongs in the bucket.
7. Liver: Pack, Pringle, Pray. If it is not bleeding, don't mess with it.
8. Packing is an art. Be an artist.
9. Retrohepatic hemorrhage: make the diagnosis early, communicate with the folks above the drapes, total hepatic isolation EARLY, repair.
10. You can't repair or resect until you've FULLY mobilized. Don't chase your target, bring your target to you.

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There are 4 degrees of intra-operative hemorrhage: 1. "Why did I get involved in this operation?" 2. "Why did I become a surgeon?" 3. "Why did I study to become a doctor?" 4. "Why was I born?."

Alexander A. Artemiev

Introduction

The management of hepatic and splenic injuries on the "homefront" has changed dramatically since the mid 1990s. The impetus for this change has been driven largely by improvements in diagnostic and interventional capabilities facilitating non-operative therapeutic strategies for blunt trauma. This chapter is not written with the "homefront" in mind. The deployed surgeon is often faced with complex challenges which must be dealt with using only a modicum of diagnostic information and clinical judgment. In the civilian setting, most of us have become experts at managing liver and spleen injuries by taking a lot of pretty pictures of them and sometimes calling in Interventional Radiology to control active bleeding. In the combat setting, you can expect to actually operate on the spleen and even the dreaded liver. Have a battle plan in mind before you make your incision, keep it simple, and you will become the master of the solid organs.

Basic Concepts

Although each patient and injury is unique, the application of a standard and conservative approach will optimize management, minimize the risk of missed injury, and improve outcomes. Conservative in this circumstance means "surgery". All penetrating injury to the peritoneum requires exploration. In contrast to the civilian trauma setting, there is almost NO role for non-operative management of blunt splenic injury on the battlefield with the exception of low grade injuries with no fluid or minimal fluid within the abdomen. Splenic injury is an "old school" surgical disease. Blunt hepatic injury can be managed non-operatively, particularly if the hematoma is intraparenchymal and there is no gross extravasation of contrast. Especially in the mature theater with expeditious strategic air evacuation, do not evacuate your patient to level IV if you do not think they are ready.

Before delving any deeper into the specifics of the surgical management of liver and spleen injury, it is important to be familiar with a few of the broad overarching concepts with respect to abdominal trauma. Several issues must be entertained when dealing with the casualty with abdominal injury including the necessity for operation, the concept of damage control resuscitation, and exposure. The issue of requirement for operation has been dealt with in Chap. 5, but in general "do not let the skin stand between you and the diagnosis", particularly in the unstable patient with the potential for abdominal injury. After injury in a combat zone, casualties are attended to by combat life savers and medics in austere environments with limited resources. These pre-hospital providers have been given the tools for airway management and peripheral hemorrhage control, but have not been fielded any capability to mitigate non-compressible truncal hemorrhage. This fact in combination with medical evacuation time and operational contingencies means that many casualties with abdominal injury will arrive to the medical treatment facility in shock with attendant hypothermia, acidosis and coagulopathy. The surgeon needs to act quickly to prevent and correct the further evolution of the trauma "lethal triad". Metabolic acidosis is a consequence of hypovolemia and inadequate tissue perfusion. Hypothermia is due to lack of intrinsic thermoregulatory capacity. Coagulopathy results from consumption, dilution, ongoing blood loss, inter-relationships with the body's thermoregulatory controls and acid/base balance, and theoretically protein C activation. If not corrected, the lethal triad will be uniformly fatal. Consequently, it is vitally important to have substantial resuscitative resources in addition to surgical resources at facilities that do stabilizing surgical care.

Contemporary military data suggests that the requirement for a massive resuscitation can be predicted by simple parameters available clinically or with point of care testing in the resuscitation area of the medical treatment facility (MTF):

- Pattern recognition
  - Bilateral proximal amputations
  - Truncal bleeding and one proximal amputation
  - Large chest tube output
- Base deficit ≥ 5
- INR ≥ 1.5
- SBP ≤ 90 mmHg
- Temp ≤ 96°F

If, in the clinical judgment of the surgeon, a massive transfusion will be required, then the damage control resuscitation concept should be utilized including a balanced ratio of plasma to red blood cells to platelets (if available). The availability of component therapy may be adequate at level III facilities depending on the stage of the conflict. However, level II facilities are not routinely as well resourced with blood and blood products so the surgeon should liberally call for fresh warm whole blood when utilizing the damage control resuscitation paradigm at these sites. See Chap. 4 for a detailed discussion of these concepts and practices.

Diagnosis

Penetrating abdominal trauma does not require an extensive diagnostic evaluation, and usually belongs in the OR for an exploratory laparotomy. If the mechanism is single or several projectiles (gunshot wounds) then plain X-ray of the chest and pelvis are helpful to identify locations of the missiles or fragments. Don't forget to do a pericardial ultrasound unless you have already decided to do a pericardial window in the OR. In the “unstable” patient, just go to the OR and figure it out there. A more common scenario in modern conflicts will be the patient presenting with multiple small wounds from an explosive device, many of which may be superficial, as well as a blunt component from the blast or vehicle crash. Evaluate these patients with a good physical exam and a trauma ultrasound (FAST) to triage them to CT scan or the OR. Unstable or peritonitis should go right to the OR, otherwise a CT scan is very helpful for delineating the number, location, and depth of penetration of the projectiles as well as any intra-abdominal injury.

Once you have diagnosed an injury to the liver and/or spleen, now comes decision time. The number one factor is always patient stability, followed by your physical exam and imaging findings. However, in the combat setting you must also consider your nonoperative interventional capabilities (usually none), your ability to closely and serially observe the patient (usually limited), your bed and ICU capacity, your blood bank capability, and whether this patient will need to be sent through the evacuation chain (relatively unattended) any time soon. All of these factors usually weigh much more heavily in favor of operative management rather than observation only. Of course there are exceptions, but these are relatively infrequent. You can consider nonoperative management for very low grade injuries (Grade I or II at the most) with no evidence of bleeding, no other injuries requiring operation, and in a patient you can observe for at least 48–72 h. Otherwise the best option is usually the old school solution and just “heal with steel” in the operating room.

Exposure

Though many alternatives are available, the midline incision is the most expedient and versatile incision for opening the abdomen. This incision can easily be extended into a median sternotomy for exposure and control of the inferior vena cava which may be necessary, particularly in patients with retrohepatic vena cava injury. Remember that once the peritoneal cavity is entered, the exploration should proceed in an orderly manner with the priorities of hemorrhage control, contamination control, and definitive repair if possible/warranted. Subcostal extension of the incision may be useful for optimum exposure, particularly for management of hepatic injury.

Do not skimp on your exposure! I repeat, do not skimp on your exposure! Attempting a “mini-laparotomy” or the “just take a peek” approach is usually only a time waster – in patients who often don’t have extra minutes to spare. To adequately pack, mobilize, and operate on the liver and spleen the upper extent of the incision has to be to the xiphoid, so make a full laparotomy incision from the start. If you are entering the case later or get called to assist on a difficult laparotomy, the best contribution you can usually make right away is by extending the incision and improving exposure. You will be amazed at how quickly tough cases turn into “chip shots” when you do this.

Are You a "Packer" or a "Sucker"?

Should you begin your laparotomy by doing a full four quadrant packing, or just suction out the blood to identify the bleeding area and get to work? These two warring factions will never completely agree on the best approach to the trauma laparotomy with hemoperitoneum, but each has its applications and advantages. Many very experienced trauma surgeons have discarded the oft repeated mantra of "pack all four quadrants" and either do focused packing in the area of injury, or do no packing and simply start suctioning and looking for the injury that is bleeding the most. This approach is great for injuries to a single area or vessel that you can quickly identify and control, and avoids wasting time and supplies. It may be less appropriate for the inexperienced trauma surgeon or for injuries to multiple areas with large volume hemorrhage and patient instability. What is clear is that haphazardly throwing a bunch of lap sponges into a large pool of blood does nothing for exposure or hemorrhage control. Packing is an art, so be an artist.

Before you open the peritoneum, make sure the tech has a pile of lap sponges ready to go (unfolded) and more available. Your standard suction tip will become clogged immediately, so have at least one (or more) Poole suction catheter attached and ready. If you encounter a large volume of hemoperitoneum (the "Mt. Vesuvius" effect) then your initial packing is not done for hemostasis but instead is meant to absorb and remove blood. Rapidly place two or three packs at a time into and then immediately out of the abdomen, while also continuously suctioning the cavity and scooping out large clot with your hands. This will rapidly clear the field even with high volume bleeding and allow you to plan your next move. Now is the time to do your packing of the abdomen, which can usually be focused on the right and left upper quadrants unless there also a pelvic source of hemorrhage.

Packing the left upper quadrant to control splenic bleeding should accomplish two goals: (1) stopping hemorrhage and (2) moving the spleen into the surgical field for better visualization and manipulation. This is best done from the right side of the table with manual or self-retaining retraction of the left costal margin (see Fig. 8.1). Use your right hand to cover the spleen and retract it inferiorly, then place several packs in the space between the spleen and diaphragm. Next cup the spleen with your right hand and retract it toward you, placing packs behind it. Often just these two maneuvers will halt hemorrhage, but if not then additional packs can be placed directly over the spleen or use manual pressure.

Packing the right upper quadrant to control liver bleeding is more difficult, and requires mobilization of the liver as well as properly placed packs to effect any substantial compression (Figs. 8.1 and 8.2). You have the same goals as with the spleen of stopping hemorrhage and improving your exposure of the injured organ, most of which is accomplished by displacing the liver caudally as much as possible. Remember that the best way to immediately control a major hepatic laceration or "burst" injury is with your hands and manual compression. Do this prior to performing a full mobilization and packing in the unstable patient to allow some anesthesia catch-up time. Next quickly divide the falciform ligament and continue

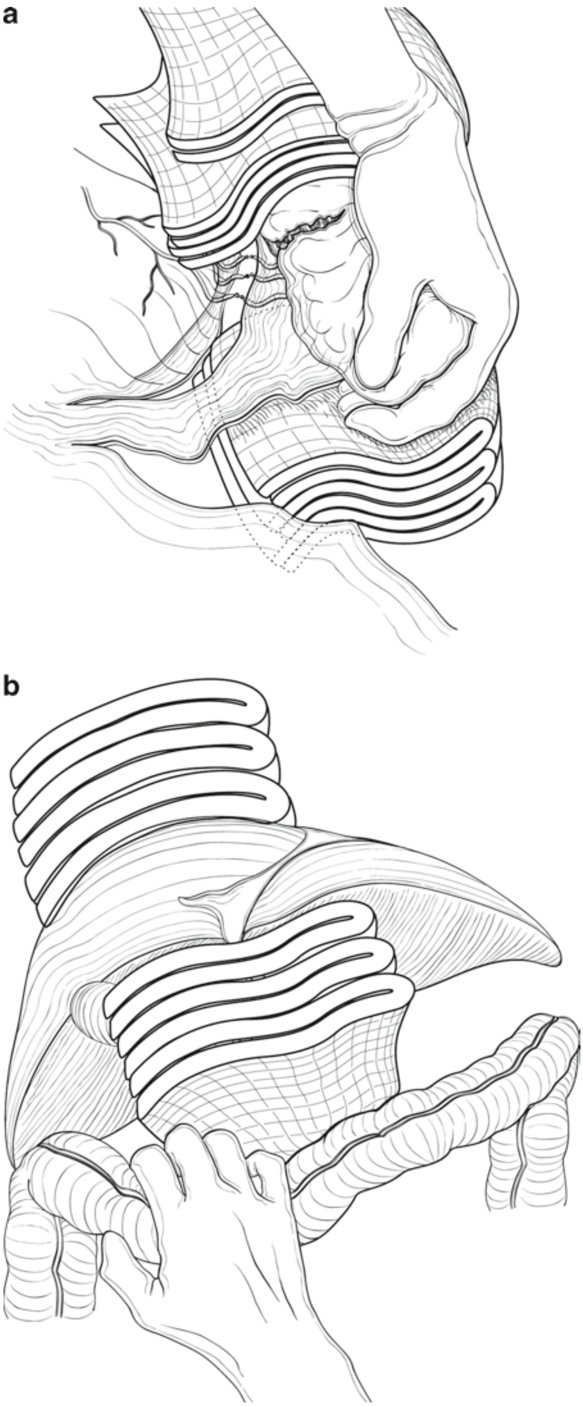

Fig. 8.1 Packing of abdominal solid organ injuries. (**a**) Retract the spleen inferiorly and medially to pack above and behind the organ first, then you can add packs over the top. (**b**) Packing of the liver requires packs above and behind the dome as well as inferiorly. This will also mobilize the liver into your surgical field

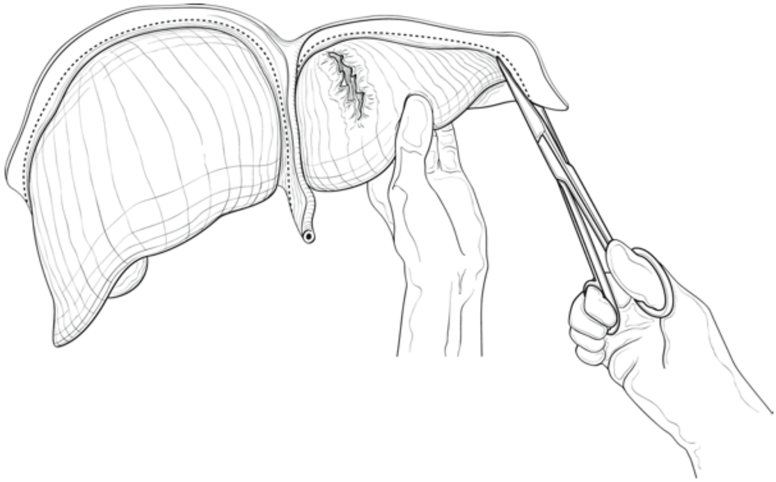

Fig. 8.2 The liver will be only minimally mobile until you release the ligamentous attachments to the anterior abdominal wall (falciform), diaphragm, and lateral abdominal wall

straight down the coronary ligament with a bovie or scissors, allowing retraction of the liver away from the anterior abdominal wall. Mobilize the left lobe by division of the triangular ligament starting laterally and proceeding medially, taking care to not proceed too medial and injure the left hepatic vein or vena cava. Mobilize the right lobe by using leftward retraction to expose the lateral attachments (coronary and right triangular ligaments) and divide sharply or with bovie. Take care that as you roll the liver medially not to tear or injure the multiple small direct branches to the vena cava. The liver, and particularly the right lobe, should now be mobile enough to retract inferiorly and medially into your field (Fig. 8.2). Place packs behind and above the right lobe, and left lobe if needed.

Spleen

The spleen should be carefully evaluated by gentle traction of the organ caudally and medially. With this manipulation technique, the spleen can be mobilized to near the midline in an atraumatic fashion. Any injury to the spleen should be investigated thoroughly. Small capsular tears or lacerations that are non-bleeding or those in which the bleeding can be controlled with simple electrocautery can usually safely be left in situ. However, higher grade splenic injuries not amenable to simple hemostatic surgical techniques should be treated with splenectomy. Unlike the civilian environment in which some of the intermediate grade splenic injuries can be managed with surgical salvage therapies such as hemisplenectomy, extensive suture repair, or prosthetic wraps, the contingencies of the combat environment, especially the evacuation intervals without the capacity for surgical therapy preclude the utilization of splenic salvage for most patients.

Once the decision has been made to perform a splenectomy the spleen is retracted medially and the ligamentous attachments to the colon, left kidney, peritoneal surface and diaphragm are taken down. Not infrequently, the dissection plane has already been developed by the splenic hemorrhage and this mobilization can be done bluntly. Once mobilized, the vascular attachments to the spleen can be ligated sequentially or en masse. The major vascular pedicle into the hilum should be suture ligated with a heavy braided suture. Alternatively, a linear stapler with a vascular staple load can be used to rapidly divide the hilum providing excellent security and hemostasis (Fig. 8.3). Always assess the tail of the pancreas – if it is

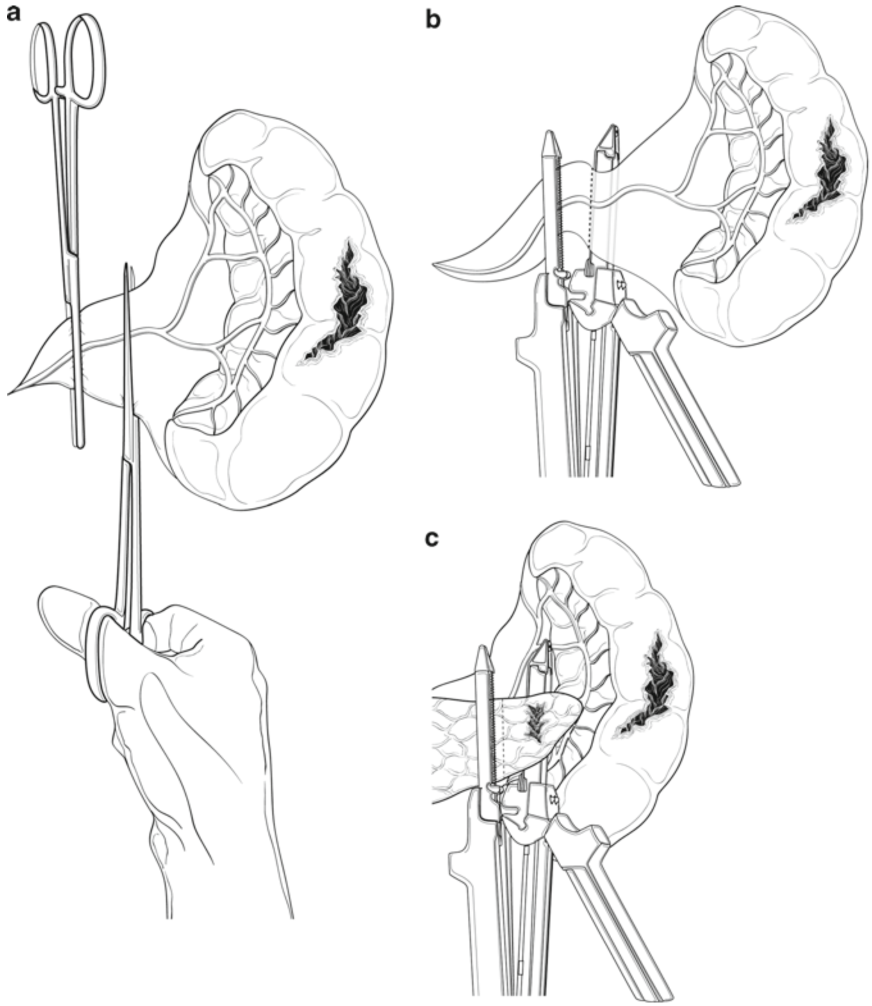

Fig. 8.3 Techniques for a trauma splenectomy include (**a**) en masse hilar clamping and ligation, (**b**) linear stapled splenectomy, and (**c**) linear stapled splenectomy with distal pancreatectomy

injured or intimately adherent to the splenic hilum, simply fire your stapler proximal to this to include the pancreatic tail with the specimen. In this scenario I would always leave a closed-suction drain, otherwise it is usually not needed. VERY IMPORTANT: do not underestimate the capacity of the short gastric vessels to cause problems. After the spleen has been removed, it is important to reexamine the splenic bed and the greater curvature of the fundus of the stomach to ensure adequate hemostasis. Grasp the greater curve of the stomach with your hands and progressively squeeze it along its entire length. You will often dislodge some clot and identify bleeding short gastric vessels that you might have otherwise missed. Ligate or clip these securely, and remember that gastric distension will overcome poorly tied ligatures.

Liver

If hemorrhage is emanating from the right upper quadrant, the strategy is different. Since the liver is not a wholly resectable organ, efforts are tailored toward hemorrhage control in situ. Do not attempt a major hepatic resection in a damage control setting unless you have no other option! The first technique to control bleeding is hepatic packing and is done with laparotomy pads around the liver to grossly restore the anatomy of the liver as described above. An adjunct to this technique is the addition of topical hemostatic agents into/around the hepatic laceration. In many instances, this is the only technique that is required to control hemorrhage. It is vital for the surgeon to understand the solid organ packing concept and be facile with the technique.

If packing or reconstitution of the hepatic anatomy by compression is ineffective, then a Pringle maneuver should be the next step. This maneuver is the initial hepatic vascular control technique and is effected by the surgeon passing the left hand into Morrison's Pouch posterior to the porta and subsequently placing the left thumb on the gastrohepatic ligament so that only a small veil of tissue is present between the thumb and forefinger. At this point, a window is created in the gastrohepatic ligament and an umbilical tape passed to encircle the porta (Fig. 8.4). A Rummel tourniquet can be utilized for subsequent temporizing control. The porta can similarly be controlled with a vascular clamp but these tend to be cumbersome as they are less maneuverable. The Pringle is both a diagnostic and therapeutic technique. By compressing the porta hepatis, the hepatic inflow from the common hepatic artery and the portal vein are compressed. As a diagnostic strategy, this is a useful tool because if the bleeding is controlled by the maneuver, then the hemorrhage is largely intraparenchymal vascular in nature. If, on the other hand, the Pringle fails to mitigate the hemorrhage, then the hemorrhage is likely due to hepatic vein or retrohepatic vena cava injury. From a therapeutic standpoint, if the hemorrhage is controlled by this technique, then that allows the surgeon gross hemostatic inflow control while attempting to develop more definitive control measures. In general, the Pringle maneuver can be applied for approximately 60 min. Start your timer and keep track of the duration on clamp!

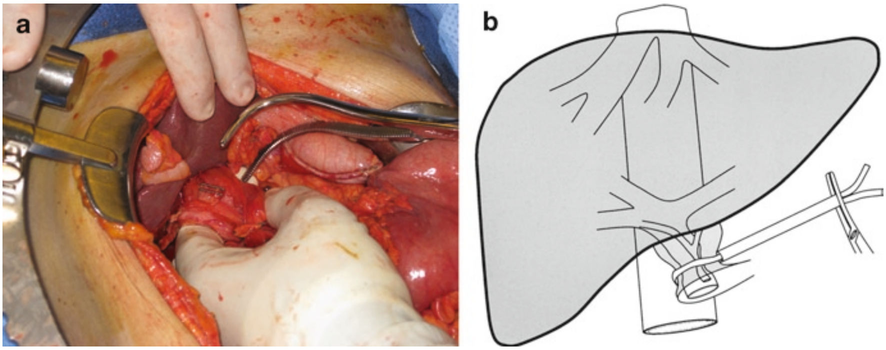

Fig. 8.4 Intraoperative photo of the Pringle maneuver. The portal triad including the common bile duct, portal vein, and hepatic artery has been encircled and is ready for a clamp (**a**) or Rummel tourniquet (**b**). (*Panel b* is reprinted with permission from Abdalla et al., Surgical Clinics of North America 2004;84:563–585)

The management of parenchymal liver wounds depends upon the site and severity of the injury. Devascularized peripheral or segmental injuries should be managed by resectional debridement. This resectional debridement can be done with finger fracture techniques and direct suture ligation of remaining structures or with a GIA stapler utilizing a vascular load. However, there is little role for anatomic surgical resection in the acute post-injury setting. If hemorrhage is coming from deeper within the liver substance, then a hepatotomy should be developed by incising the overlying Glisson's capsule followed by finger fracture of the hepatic parenchyma with direct ligation of vessels and biliary structures. Once the main vascular structures are isolated and controlled, packing and adjunctive topical hemostatics are often useful to maintain hemostatic control. An adjunct for management of dead space within these large hepatotomies, particularly at subsequent operation, is the placement of a pedicled omental flap within the wound and closure of the overlying hepatic parenchyma. This is accomplished utilizing 0-chromic suture on a liver needle taken in deep bites through the peripheral liver substance to close the hepatotomy.

One noteworthy injury that can be extremely challenging in the austere environment is the transhepatic missile injury with hemorrhage. The quandary in this instance is that the bleeding site could be anywhere along the tract and a large hepatotomy is not feasible. In this circumstance, it may be possible to tamponade the deep parenchymal hemorrhage with a balloon tamponade device (see Fig. 8.5). The device which can be made by passing a red rubber catheter (or nasogastric tube, foley catheter, etc.) with side holes cut out through a Penrose drain ligated proximally and distally onto the red rubber catheter. The red rubber catheter is then passed gently through the tract. Once through the tract, the red rubber catheter is clamped distally and the Penrose is inflated with saline to effect tamponade. Then the proximal end of the red rubber catheter is clamped. One last potential therapeutic option in the patient with ongoing hemorrhage from deep within the liver substance

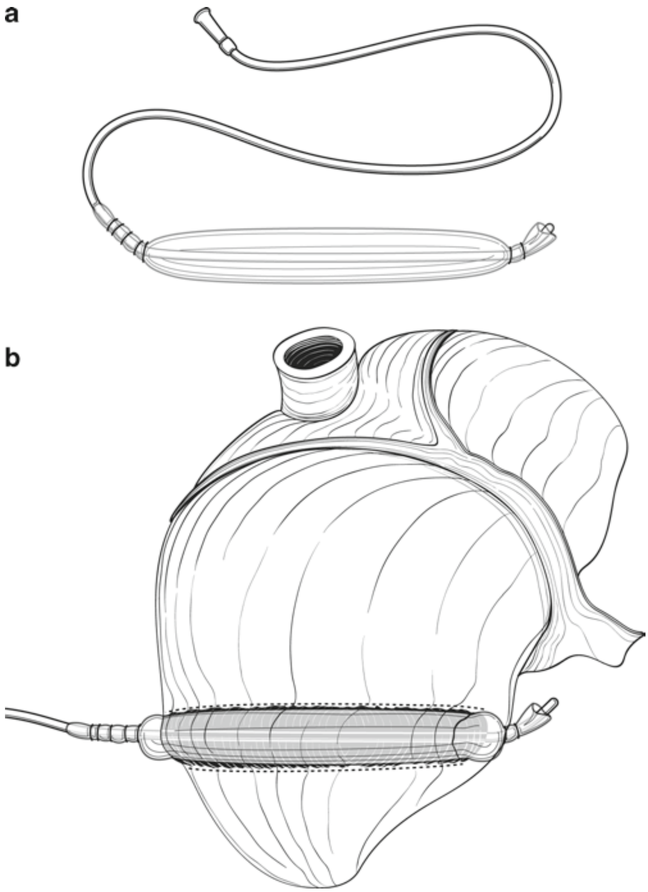

Fig. 8.5 Balloon tamponade for through and through liver injuries

which is difficult to control either due to depth or degree of hepatic destruction is selective ligation of the associated major branch hepatic artery. Often, the portal vein can maintain the viability of the liver substance. If the diaphragm has been violated in conjunction with the hepatic injury, fix the diaphragm in order to minimize the potential development of a bronchobiliary fistula (a very morbid and frequently lethal complication).

"Audible bleeding" with the Pringle applied requires decision and action. First, you must consider context. Management of an injury to the retrohepatic vena cava or hepatic venous complex requires a tremendous amount of resources including blood/blood products, OR time, personnel, and equipment, many of which are in limited supply in the forward environment. If you are in a true mass casualty scenario, you may have to make an on the table decision to triage this patient as "expectant". This incredibly difficult situation is one that few surgeons are prepared for or have experience with, but should be made if one critical patient will utilize

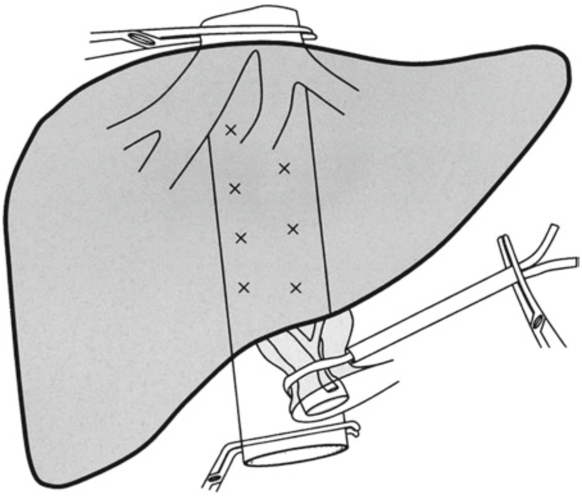

Fig. 8.6 Diagram of total hepatic vascular isolation by controlling the portal triad, infrahepatic vena cava, and suprahepatic vena cava. The aorta should also be cross-clamped in anticipation of the hypotension caused by this maneuver. (Reprinted with permission from Abdalla et al., Surgical Clinics of North America 2004;84:563–585.)

critical resources that could salvage multiple others. On the other hand, if resources are available then once the diagnosis is made, there can be no wasted steps or time. If packing will control the hemorrhage, then pack and get out of the OR. Often, packing will not ameliorate the hemorrhage and the surgeon much quickly begin steps aimed at total hepatic isolation (Fig. 8.6). It is incumbent upon the surgeon to COMMUNICATE with anesthesia the gravity of the injury.

This procedure is much easier to draw or describe than it is to execute. To begin, the aorta should be crossclamped at the diaphragmatic hiatus in order to preferentially perfuse the heart and brain. Then perform a right medial visceral rotation and a Kocher maneuver to gain access to the infrahepatic/suprarenal IVC and encircle with a Rummel tourniquet or vascular clamp. To control the suprahepatic IVC, you may have to perform a median sternotomy and pericardotomy and encircle the IVC immediately below the right atrium. It is critically important for the anesthesia providers to have lots of access above the diaphragm in preparation for clamping the IVC. Once the liver inflow is controlled, rapidly mobilize the liver by taking down the falciform ligament and the right triangular ligament. Having done this, the liver can be "rolled" and reflected to the left for exposure of the retrohepatic vena cava and hepatic veins for repair. Atriocaval shunting may be a damage control alternative, particularly in the resource constrained environment, but this is a "last ditch" effort (Fig. 8.7). To perform an atriocaval shunt, the surgeon uses the isolation techniques mentioned previously. However, instead of clamping the vena cava above and below the liver, a large chest tube (or endotracheal tube) has several side holes cut proximally where the bypass conduit will rest in the right atrium. A pursestring suture is placed at the apex of the right atrium and then the atrium is incised.

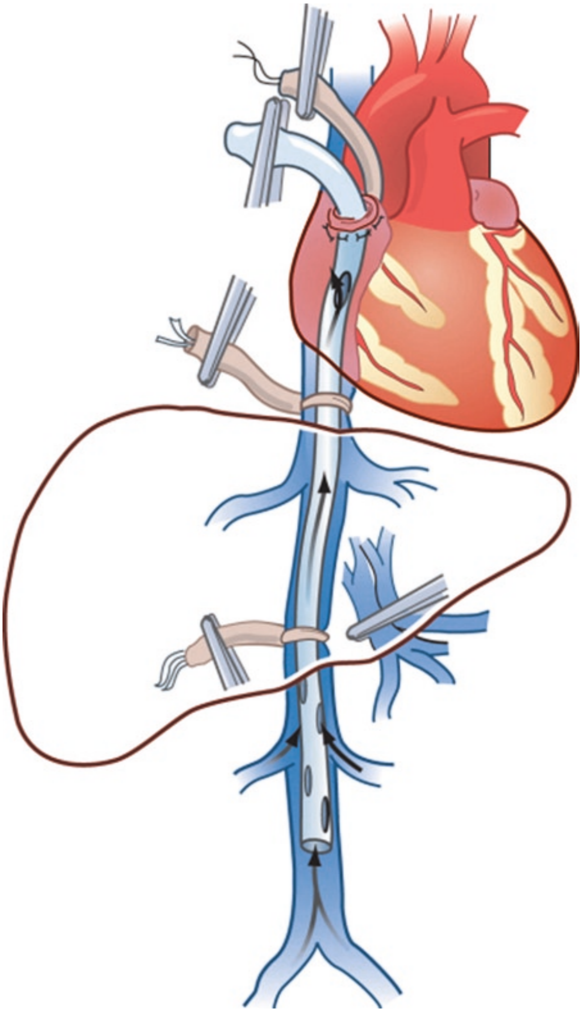

Fig. 8.7 Placement of an atriocaval shunt using a chest tube passed through the right atrium to the infrahepatic vena cava. An endotracheal tube can also be used and the cuff is then inflated to occlude flow around the tube. (Reprinted with permission from Townsend et al. eds, Sabiston Textbook of Surgery 18th edition, Elsevier Publishing 2007.)

The chest tube is fed down through the atrium down the vena cava so that all of the distal drainage ports are below the infrahepatic Rummel tourniquet which is then snugged down upon the chest tube. The proximal chest tube should be positioned so that all of the newly cut side holes reside within the right atrium Then, the suprahepatic Rummel tourniquet is then cinched down and the atrial pursestring tied securely. Then proximal end of the chest tube can be used for high volume infusion. With all this being said, the outcome of the battlefield casualty with retrohepatic vena cava/hepatic vein injury is almost uniformly fatal.

Always be thinking about the patient's clinical status. Does anesthesia need to catch up? Is the patient cold, coagulopathic, acidotic? If hemorrhage is controlled and the patient requires further resuscitation, it is often best to terminate the procedure and take the patient to the intensive care unit for further resuscitation. The abdomen should be left open with the skin closed with a vacuum pack, running suture or towel clips. The advantage to the former, particularly if closed suction drains are placed under a vacuum assisted closure is that the surgeon can follow ongoing blood loss as a diagnostic strategy to time reoperation. The advantage of the latter is the tamponade effect created by the temporary abdominal closure. If the abdomen is closed, care should be taken to monitor the casualty for signs and symptoms of the evolution of abdominal compartment syndrome such as increasing abdominal distension/tightness, oliguria, increase in airway pressures or difficulty ventilating, or increased bladder pressure. You are always walking a fine line in these cases because you want some degree of abdominal hypertension to help control hemorrhage. If full blown abdominal compartment syndrome develops this mandates expeditious release of intra-abdominal pressure. This is done most safely in the operating room, particularly if the nidus for the increased intraabdominal pressure is ongoing hemorrhage.

Postop Pearls

There is nothing special about the postoperative resuscitation of the liver or spleen injury patient. Just follow the resuscitation principles outlined in Chaps. 30 and 31 with your over-riding goal being the SAFE restoration of adequate perfusion and correcting coagulopathy. If a damage control laparotomy was performed, the timing of the second-look laparotomy should be dictated by the patient physiology and not an arbitrary time period. There are several specific pitfalls or problems to anticipate after operating on a damaged liver or spleen. The number one problem is going to be recurrent hemorrhage, which should prompt an early return to the operating room. For the spleen this is almost always due to bleeding from short gastric vessels or branches of the splenic hilar vessels. For the liver it is the injured area that is now bleeding again. Do not go back and do the same thing expecting it to magically work this time. Large mattress hepatorrhaphy sutures (±pledgets) are very effective for controlling parenchymal bleeding and topical hemostatic agents or advanced hemostatic dressings (combat gauze, Quikclot, etc.) have been used with success in many cases. If a large bile leak is noted you should make all attempts to identify and suture ligate the culprit duct. If it cannot be identified then pack omentum in the area and widely drain it.

Although there is no proven role for routine post injury imaging of liver or spleen trauma, I would recommend a follow up CT scan at 2–4 weeks for all severe (Grade III or higher) liver injuries. There is a significant incidence of pathology such as biloma, abscess, pseudoaneurysm, and arterio-venous or biliary fistula with severe liver injury. These are particularly important to identify and manage appropriately in the very active and mobile patient population in combat trauma. Always make sure that the patient receives post-splenectomy vaccinations. Give these as soon as possible, preferably during the same hospitalization. The old dogma of waiting at least 2 weeks likely does nothing to improve the immune response, but definitely decreases the number of patients who actually receive their immunizations. This is best done by documentation within the medical record and direct communication to higher levels of care. Be familiar with the theater trauma system clinical practice guidelines!

The basic tenet to the management of the casualty with liver or spleen injury is to have them survive THIS operation. Remember that you will not have the multiple redundant safety nets that you have in civilian settings that make nonoperative management of even severe injuries a safe technique. Be decisive, be definitive, and remember that time-honored techniques and practices are often there for a reason. Always remember: It is a long chain of survival for the combat casualty and all of the links must be strong.

Chapter 9
Pancreatic and Duodenal Injuries (Sleep When You Can…)

Tommy A. Brown

Deployment Experience:

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Attending Surgeon, 160th Forward Surgical Team, Naray, Afghanistan, 2007

BLUF Box (Bottom Line Up Front)

1. The indication for a trauma Whipple is rarer than hen's teeth. You don't want to go there.
2. A trauma laparotomy is not the time to learn to do a complex pancreatic surgery.
3. For both pancreatic and duodenal trauma, drains are your best friends in the world.
4. You have to look at both the stability of the patient and the complexity of the injury to make a good decision.
5. Keep in mind that the majority of injuries involving the head of the pancreas and the duodenum will either require no direct repair or multiple operations to correct.
6. Beware the trauma sins of omission – every trauma exploration should include a look at the pancreas and duodenum. These injuries kill if missed.
7. Assume your duodenal repair will leak, so see point 3 above.
8. Primary repair and wide drainage of the duodenum usually beats any of the complex reconstruction methods you may have read about.
9. A stapled distal pancreatectomy is usually your simplest option for significant injuries to the body and tail of the pancreas.
10. Para-duodenal hematomas are duodenal or vena cava injuries until proven otherwise. Explore them – but be prepared for both blood and guts.

For pancreatic trauma: treat the pancreas like a crawfish, suck the head … eat the tail.

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M. Martin and A. Beekley (eds.), *Front Line Surgery: A Practical Approach*,
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I have a unique perspective here. I am a surgical oncologist who has the benefit of being exposed to the intense trauma surgery of war. I take trauma call in a level 2 trauma Center and I have been deployed to the busiest combat support hospital's in Iraq as well as being deployed to a desolate forward surgical team in Afghanistan where the only help I had was the skills I possess. I remember saying to the editor of this book (and good friend), "Any surgical oncologist can be a trauma surgeon because we are comfortable operating anywhere in the body and we routinely operate on the pancreas and the liver." Obviously, that was an incorrect statement because the trauma patient has a very distinct physiology requiring attention to much more than just the technique of how to do a complex surgery. This was a lesson that I learned the hard way. On the flip side, pancreatic and duodenal injuries can be very difficult to manage if you do not routinely operate in this area. For a surgeon who does not have experience in complex operations and those involving the pancreas and the duodenum, the midst of the acute trauma is not the time to try to learn. To this end, there are excellent bail-out options available to ensure the safety of the patient and bring about the best chances of long-term survival. If you are a surgeon then you know the saying "Eat when you can, sleep when you can and don't mess with the pancreas." Another wise Army surgeon has also told me "I don't fear the pancreas as much as I fear the duodenum". This has never been as true as in the combat trauma patient with an injury in that dreaded right upper quadrant. The goal here is to get an overview of the most appropriate treatment beginning with the simple injuries of the pancreas and duodenum and progressing to the more complex injuries, always keeping in mind the stability of the patient in selecting the best management of each of these injuries.

Making the Diagnosis

Most often in the combat scenarios, you will discover these injuries during abdominal exploration for penetrating trauma and massive blast injury. No diagnostic studies are required in these cases, just a thorough exploration. However, you may also encounter patients that are more analogous to civilian trauma, with primarily blunt trauma to the abdomen and no obvious indication for emergent exploration. You should approach these patients similar to a civilian blunt trauma, with the exception of having a much lower threshold for exploration if an injury is in question. This is particularly important for soldiers or other patients that you are putting into the evacuation chain and who will not be closely observed by a surgeon over the next 24–48 h. In addition, there is now a large body of civilian literature on nonoperative management of pancreatic injuries. This usually relies on having a variety of advanced adjuncts available (angiography, ERCP, interventional radiology) and adequate resources and personnel to provide the long term care that is often required. This will not be the situation at a forward combat medical facility, so in many cases the "conservative" approach to these injuries is to operate and take care of it with one procedure.

You should suspect a blunt pancreatic or duodenal injury in any patient with a direct blow to the upper abdomen, blast trauma, or blunt abdominal trauma with a lumbar spine fracture. These injuries are notoriously difficult to diagnose due to the retroperitoneal location which may limit or delay the development of peritoneal signs, as well as the limitations of imaging studies. CT scan is great for almost all serious abdominal injuries – except the pancreas and duodenum. It has a sensitivity of between 40 and 70%, and cannot delineate the presence of a pancreatic duct injury, particularly when performed early. Admission enzyme levels (amylase, lipase) are also of limited value in the early diagnosis, but typically will rise over the first 24 h if there is a significant injury; if you suspect an injury, then trend the enzymes over the first 24–48 h. Suggestive signs to look for on CT scan are a peri-pancreatic hematoma, free fluid in the lesser sac, or the development of a cystic fluid collection involving the pancreas. If you suspect the diagnosis but are unsure, or have an equivocal initial CT scan, I would recommend performing a delayed CT (12–24 h) scan with a small amount of oral contrast delivered immediately prior to the scan to opacify the c-loop of the duodenum. Also follow enzyme levels (which should rise), the abdominal exam, and the urine output. If your clinical evaluation and imaging studies are suspicious, then you are usually better off exploring the patient. The longer the patient sits with an undrained pancreatic or duodenal injury, the fewer options you will have for successfully repairing it due to tissue damage from leakage of enzymes or enteric contents.

Anatomy: The Key to the Battle Plan

The heat of battle in the operating room is not the time to be trying to remember your medical school anatomy, or whipping out an atlas. You should know the basic maneuvers to expose the pancreas and the critical *surgical* anatomy of the pancreas and duodenum (Fig. 9.1). This is an area that is often relatively unfamiliar to general surgeons so spend some time reviewing it and mentally rehearsing maneuvers before you deploy.

Exposure of the head of the pancreas and the 2nd/3rd portion of the duodenum is done by first mobilizing the hepatic flexure of the colon inferiorly and medially (Fig. 9.2a). Sharply open the white line of Toldt along the ascending colon and continue this around the flexure, retracting the colon inferiorly and the gallbladder superiorly. Once that first layer is opened, the rest can usually be rapidly done with blunt finger dissection and bovie. Follow the colon mesentery to the base and this will lead directly to the c-loop of the duodenum. Now you have the anterior surface of the duodenum and pancreatic head exposed. If this appears completely normal, no further mobilization is required. If complete visualization or mobilization is required, then divide the postero-lateral attachments of the duodenal c-loop as you retract it anteriorly and medially (Kocher maneuver). Beware that the c-loop is sitting on top of the vena cava as you begin this maneuver. Slide your hand behind the head of the pancreas and bluntly mobilize and palpate. Exposure of the body

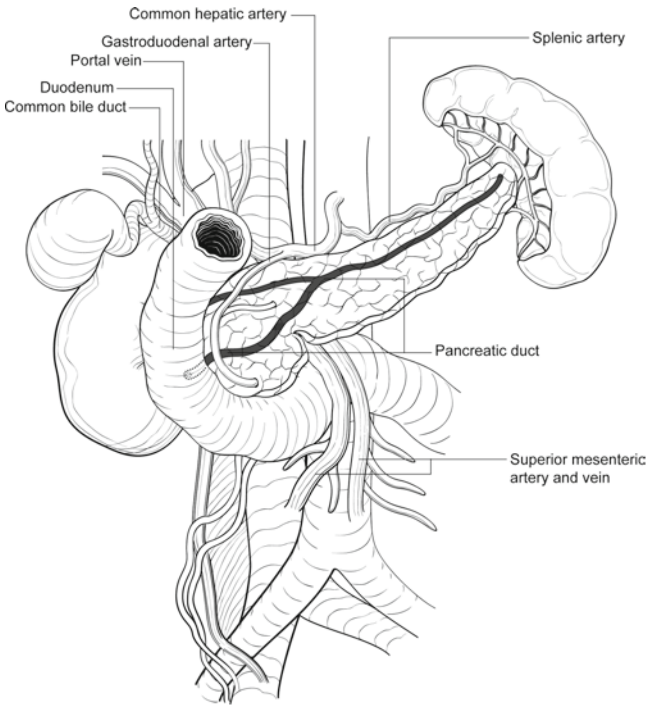

Fig. 9.1 Surgical anatomy of the pancreaticoduodenal complex

of the pancreas is easily obtained by opening the gastro-colic ligament and retracting the stomach superiorly and anteriorly (Fig. 9.2b). You can also visualize most of the tail through this window in the lesser sac. To fully mobilize the tail and splenic hilar vessels, the lateral attachments of the spleen are divided and the spleen and pancreas are mobilized to the midline together (Fig. 9.2c). Further exposure of the posterior pancreas and the fourth portion of the duodenum can be obtained by opening the retroperitoneum along the inferior border of the pancreas, and dividing the ligament of Treitz.

Figure 9.1 demonstrates the critical anatomy in this area. The vena cava and right renal vein will be immediately posterior to the duodenal c-loop. The first major vessel you encounter when exposing the body of the pancreas will be the splenic artery running (often tortuous) along the superior pancreatic border. The splenic vein is *posterior* to the pancreas, so additional mobilization will be required to expose this vessel and you must take great care when dissecting circumferentially around the body of the pancreas. There are multiple small pancreatic branches entering the splenic vein, and these will be the usual sources of bleeding during mobilization. The splenic vessels and the tail of the pancreas will then converge in the hilum of the spleen, with a wide variety of anatomic variants. Beware that the pancreatic tail may be intimately associated with the spleen, and that the splenic vessels may enter the hilum as multiple smaller branches rather than single large trunks.

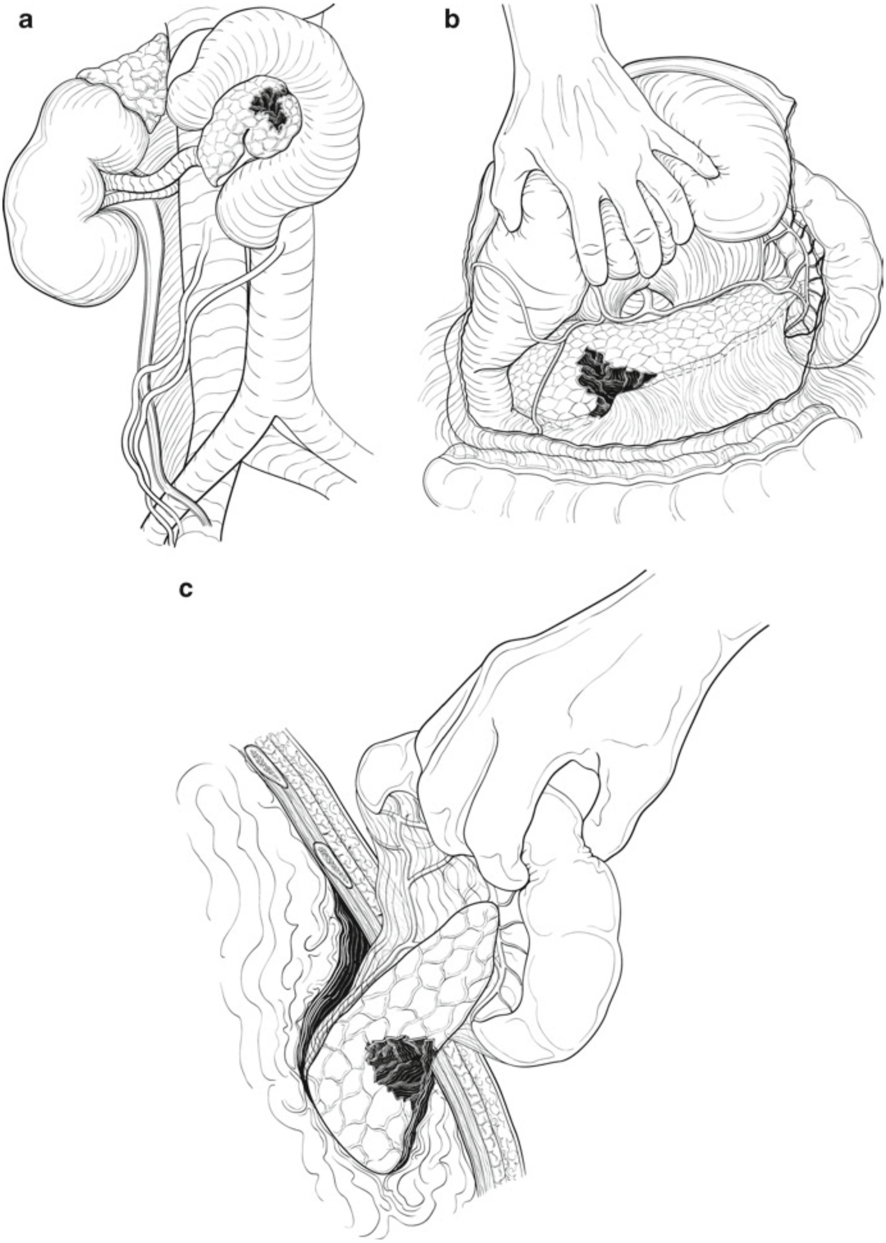

Fig. 9.2 Surgical exposure of the pancreas and duodenum. (**a**) Exposure of the head of the pancreas and duodenum is obtained via a generous Kocher maneuver. (**b**) Exposure of the body and tail of the pancreas by entry into the lesser sac. (**c**) Complete exposure of the tail of the pancreas requires lateral to medial splenic mobilization

The Body and Tail of the Pancreas

When we talk about the body and tail of the pancreas, we are referring to the pancreas to the left of the portal vein. Injuries to this portion of the pancreas can consist of a simple contusion, deep lacerations, or complete division or disruption of the pancreas. The primary concern is injury to the pancreatic duct and the possibility of a pancreatic fistula. The management of a contusion to the pancreatic body consists of drainage with a closed suction drain. If there is a deep laceration or complete disruption of the pancreatic body or tail, then a distal pancreatectomy and splenectomy should be completed. There is no place for a spleen-sparing distal pancreatectomy in combat trauma surgery. This is a technically challenging and time consuming operation in an elective setting and is not appropriate in combat trauma. A distal pancreatectomy and splenectomy is safe, quick and definitive. A closed suction drain should be left in place after any pancreatic resection.

The technical aspects of a distal pancreatectomy are very straightforward (Fig. 9.3). The pancreas should be approached by dividing the gastrocolic ligament and elevating the stomach to expose the anterior surface of the pancreas. A hematoma of the body and/or tail of the pancreas should be opened to evaluate

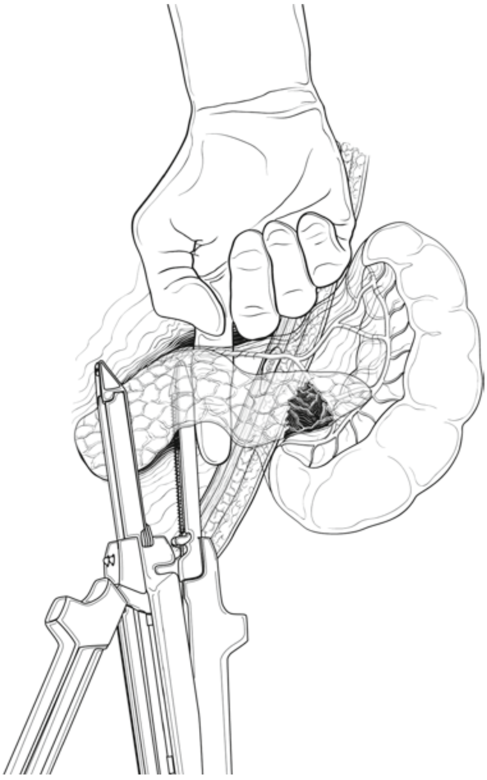

Fig. 9.3 Technique for a stapled distal pancreatectomy. Use a finger or blunt instrument to encircle the pancreas and guide a linear stapler through the retropancreatic tunnel

the anterior surface of the pancreas directly. The spleen and tail of the pancreas can be swiftly brought to the midline by placing the hand behind the spleen and pulling the spleen and pancreatic tail up as one unit, sliding the fingers in the retroperitoneal space behind the pancreas. Once the spleen is elevated, the short gastric vessels between the spleen and stomach can be divided quickly with clamps and the retroperitoneal surface packed with sponges. An important anatomic consideration is that the superior and inferior borders of the pancreas to the left of the middle colic vein are a "free zone", with no significant vessels in the area other than the splenic artery which should easily be mobilized with the body of the pancreas. With the body and tail of the pancreas now mobilized, the short gastric vessels divided, and the retroperitoneal attachments along the superior and inferior edge of the pancreas divided by electrocautery, the pancreas can now be divided with a linear stapler. I will typically use a medium staple load (linear stapler with a blue load) and divide the splenic vein and artery along with the pancreas with one staple load. I will then over-sew the artery and vein as well as the pancreatic duct if there is bleeding or if I can visualize the structures along the staple line. If the splenic artery is obvious coursing along the superior edge of the pancreas it can be divided individually; however, excessive time should not be wasted in looking for it. A technical point that should be mentioned is that a stapler occasionally will fracture the pancreatic body and you will be looking at raw edge of pancreas in some instances. This should not raise undue concern or action beyond over-sewing the duct if it can be visualized and placing a drain along the edge of the pancreas. Any retroperitoneal bleeding should be minor and easily controlled. If a topical sealant such as fibrin glue is available it can be applied over the cut edge of the pancreas and may assist in hemostasis or sealing parenchymal leaks.

This is a good place to talk about pancreatic fistulas because a pancreatic fistula is certainly possible in the procedure I just described. The important point here is that a pancreatic fistula is not life-threatening and the large majority can be treated non-operatively with full recovery. To take an excessive amount of time in a pancreatic procedure trying to avoid a pancreatic fistula will potentially cost a patient's life. Adequate drainage is all that you need to achieve in the early management of a pancreatic leak. If you are in damage control mode and plan to return within 24 h, then you do not have to place a drain – just pack and do your temporary abdominal closure. Always leave a closed suction drain prior to performing your definitive fascial closure or final exploration of the abdomen.

The ambiguous areas for injuries to the body and tail of the pancreas are those with a superficial laceration to the pancreas in which pancreatic duct involvement is unclear. My bias in these situations is as follows. If the spleen needs to be removed due to splenic injury or the vessels of the pancreas are involved, then I will generally remove the involved portion of the pancreatic tail. If none of these factors are present, and you have a very superficial laceration or contusion of the pancreas then I will typically leave a drain and move on. The preceding guidelines apply to both the stable and the unstable trauma patient, as a distal pancreatectomy and splenectomy is usually a rapid procedure with quick hemostasis.

Injury to the Head of the Pancreas

Injuries to the head of the pancreas typically involve contusions or deep lacerations, and may be associated with a duodenal injury. The most important point to establish up front is that if you don't remove the head of the pancreas as a frequent part of your elective practice, your patient will not survive the procedure in a trauma. Given this fact, the management of most pancreatic head injuries is really quite simple: stop any hemorrhage, lay drains, and get out. The majority of bleeding from the head of the pancreas can be controlled a simple suture ligation with little concern of ligating the superior mesenteric artery due to its deep posterior position. A portion of the portal vein may potentially be ligated, and this is okay if it is necessary to stop the bleeding. The only way to access the retro-pancreatic portal vein is by dividing the pancreas overlying the portal vein. From here bleeding can be controlled with vascular control of the splenic vein, superior mesenteric vein, and the portal vein at the region of the portal triad as well as multiple small branches running directly into the head of the pancreas. Given the extensive dissection required for direct access and the typical amount of bleeding associated with portal vein injury, suture ligation through the substance of the pancreas is likely the only lifesaving maneuver. I do not recommend performing a Kocher maneuver to mobilize the head of the pancreas for a contusion involving the head of the pancreas with no evidence of an expanding hematoma. However, for ongoing bleeding from the head of the pancreas, a Kocher maneuver will allow for anterior and posterior compression of the head of the pancreas for temporary hemostasis. Once bleeding is adequately controlled, closed suction drains should be placed and the operation terminated. In general, I do not recommend an attempt at bowel anastomosis to the pancreas during an initial trauma operation. This typically requires a more extensive dissection of the pancreas with division of the intestine and results in a higher fistula rate and a more difficult follow-on operation. Simply laying drains around the pancreas will handle the large majority of injuries and allow for a subsequent thorough evaluation of the pancreatic anatomy when the patient is stable and when the needed surgical expertise is available.

The Pancreatic Duct

Much of the civilian literature describes various techniques and algorithms based on trying to assess the status of the pancreatic duct. Complex procedures such as intraoperative ERCP or intraoperative direct pancreatography have been described to ascertain whether the main duct is involved in the injury. You will rarely have the ability, or the need, to do this in combat trauma. The majority of injuries can be assessed by visual inspection to determine if it is likely or unlikely that the duct is involved. It is usually obvious that destructive type injuries have involved the pancreatic duct, and that minor contusions or lacerations don't involve the duct. Either way, you should be widely draining the area and can manage the now-controlled

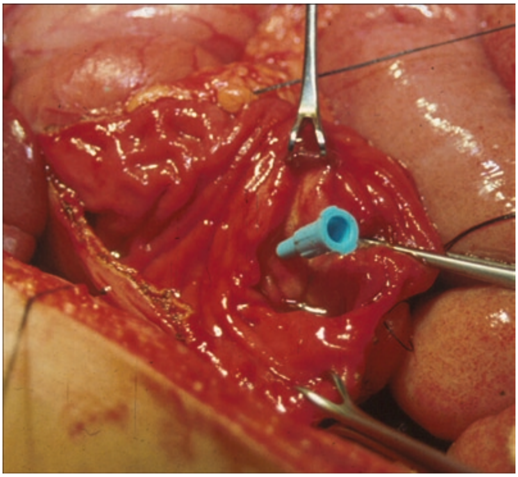

Fig. 9.4 Cannulation of the ampulla of Vater to perform intraoperative ductography. Note that this should usually only be done if the status of the duct is truly in question and there is already a duodenal injury present

pancreatic fistula at a subsequent laparotomy or non-operatively. If an assessment of the duct is absolutely critical, then I would recommend against trying to open the duodenum and cannulate the pancreatic duct, unless the duodenum is already traumatically opened (Fig. 9.4). You can access the gallbladder or the common bile duct with a butterfly needle or angiocatheter and inject contrast material and/or methylene blue dye. Allow several minutes for distribution of the contrast and observe for blue staining of the tissues or fluoroscopic evidence of contrast extravasation.

Duodenal Injuries

Duodenal injuries can range from simple lacerations to complex injuries with involvement of the duodenum, pancreas and common bile duct (Fig. 9.5). Complete evaluation of duodenal injuries should include a Kocher maneuver to fully examine the posterior wall of the duodenum (Fig. 9.6). No matter what the stability of the patient is, you should try to achieve at least temporary closure of the duodenal injury. If the patient is unstable, then just whipstitch it closed and figure out a definitive repair at a second-look operation. For definitive repair, you must assess the injury and decide if you can do a simple repair or a more complex procedure will be required. Your goal is an adequate closure that preserves the luminal area (at least 50%), protects the surrounding structures, and allows adequate drainage. Either way, assume your repair will leak and *always* leave a closed suction drain (or two) in the area.

Simple lacerations of the duodenum can be closed primarily in one or two layers after debriding the wound edges (Fig. 9.7). I prefer a single layer closure with interrupted silk suture, typically in a longitudinal fashion. Small lacerations can be closed

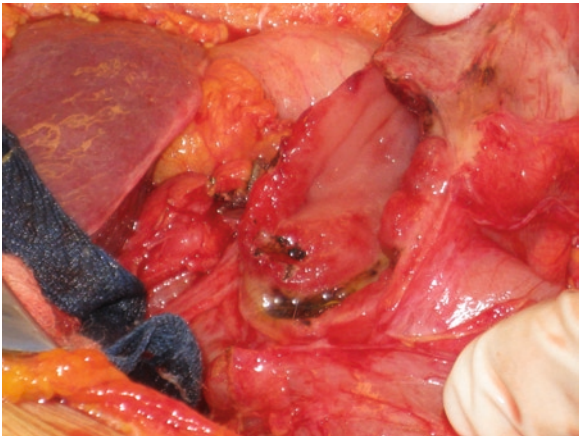

Fig. 9.5 Large laceration (>50% circumference) to the second portion of the duodenum

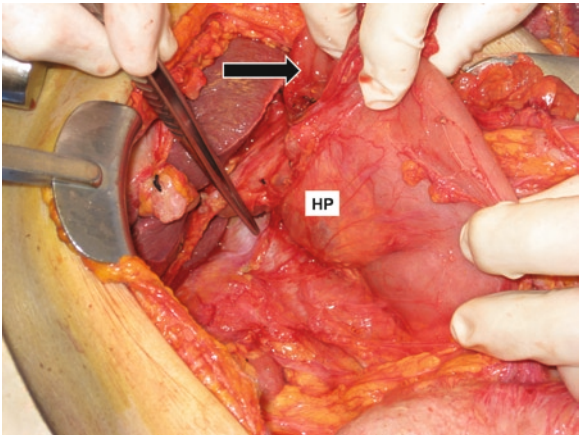

Fig. 9.6 Injury shown in Fig. 9.5 (*black arrow*) after mobilization of the duodenum and head of pancreas (HP) via a Kocher maneuver. Forceps are pointing to the inferior vena cava

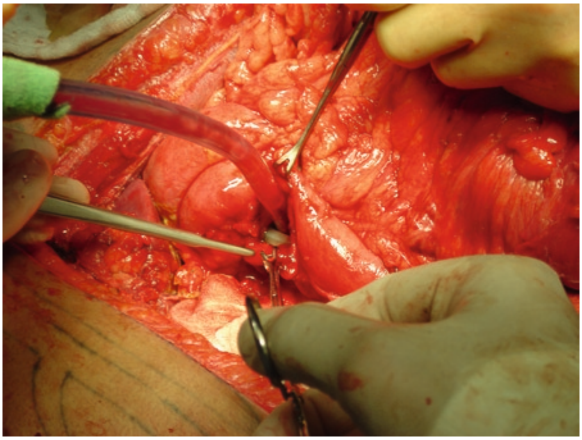

Fig. 9.7 Simple laceration of the duodenum ready for suture repair. Note that nasogastric tube has been advanced through the area of planned repair for postoperative decompression

transversely but care should be taken at the “dog ears” of the closure to ensure no leak and to ensure no undue tension on the closure due to the relatively fixed nature of the duodenum. Do not apply the typical strictureplasty technique of “longitudinal incision and close transversely” on the c-loop of the duodenum – it will create an obstructing fold. It is mandatory to identify the Sphincter of Oddi and avoid injury to this structure during closure. Drains should be placed after any closure of the duodenum, pancreas, or biliary tree.

For more extensive injuries to the duodenum with loss of a portion of the duodenal wall or requiring a complex closure of the duodenal wall, duodenal diversion is recommended. The duodenal wall which cannot be closed primarily can be addressed in two ways. A large Malecot tube can be placed in the duodenum, secured with a purse string silk suture and brought out through the abdominal wall for a controlled fistula. Note that this will often leak somewhat around the Malecot, so you still should leave closed suction drains in the area. This is the fastest and simplest option for a damage control scenario. If you have a little more time then several options are available. One often described technique is to bring a loop of jejunum up to the duodenal defect, and perform a “serosal patch” by suturing the margins of the defect to the serosal surface of the jejunal loop. I would not recommend this technique due to the high failure and leak rate. A better choice is to bring that loop of jejunum up to the defect and do a formal side to side anastomosis between the duodenum and the jejunum. This allows for much better drainage and less chance of luminal obstruction than the serosal patch option.

Following any complex or high risk type of duodenal repair you should consider whether or not to add a pyloric exclusion procedure. The theory is that you will protect your repair and decrease the chance and severity of leaks by excluding it from gastric acid and secretions. Remember that this can be done at a second-look operation and does not have to be done immediately with the duodenal repair. There is no good data that pyloric exclusion reduces complications, and it definitely adds time and complexity to your operation. I use a “gestalt” approach to exclusion – if I feel relatively confident about my repair then I don’t do it. If I have concerns, had to do a very complex repair, or have a concomitant pancreatic injury then I will perform pyloric exclusion. I recommend exclusion of the duodenum with a transverse non-cutting staple line (TA-60 blue load) across the proximal duodenum and completion of a Roux-en-Y gastrojejunostomy. Another excellent option is to make a longitudinal gastrotomy adjacent to the pylorus, evert the pylorus into the gastrotomy and sew it closed (prolene or PDS suture), and then use the gastrotomy as the site of your gastrojejunal anastomosis (Fig. 9.8). I would also recommend a feeding jejunostomy for nutritional support in these patients at the time of definitive closure. For large non-expanding hematomas overlying the head of the pancreas, I recommend placement of drains overlying the pancreas and adjacent to the duodenal sweep, with gastrostomy and jejunostomy placement. No attempt should be made to unroof this injury if there is no evidence of ongoing bleeding. If there is a strong concern for an associated duodenal injury under the hematoma, then you can perform intraoperative upper endoscopy with the duodenum submerged in saline to evaluate for any leak.

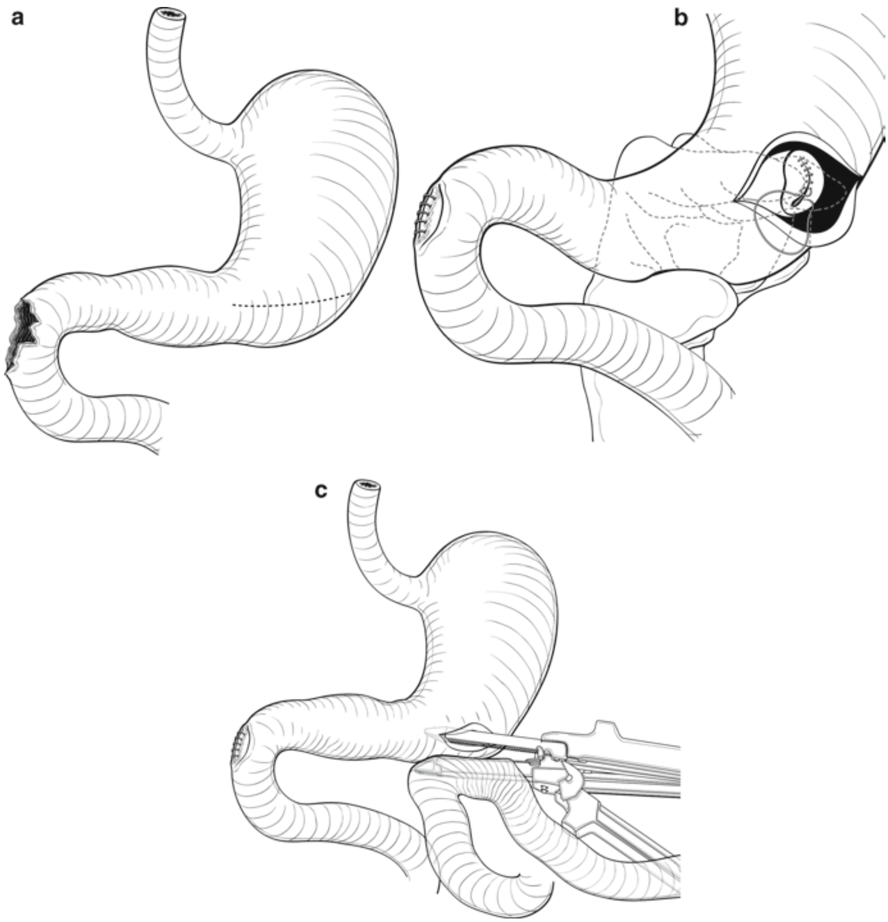

Fig. 9.8 Technique for sutured pyloric exclusion. (**a**) Incision on antrum. (**b**) Pylorus is everted and sutured closed (**c**) Gastrojejunostomy using the initial incision, duodenal injury closed

One final unique injury pattern you may encounter in combat trauma is that of multiple small fragment wounds to the duodenum. This can result in multiple injuries of various sizes, from an obvious laceration to a subtle pin-hole defect. Full mobilization of the duodenum should be performed and air or methylene blue instillation is useful for identifying occult perforations. A particularly difficult injury to identify and manage is a perforation of the mesenteric/pancreatic wall of the duodenum. You cannot mobilize the pancreatic head away from the inner duodenal wall to adequately expose and repair these injuries. If you suspect or identify one of these injuries, then an excellent option is to open the duodenum by performing a longitudinal duodenotomy along the anti-mesenteric border, and inspect the inside surface for injury. Always locate the major ampulla before suturing things closed if you are in the second/third portion. You can easily repair these defects with full-thickness interrupted sutures from the inside, and then close the duodenotomy with running or interrupted silk suture.

The Trauma Whipple

A full description of the technical aspects of a pancreaticoduodenectomy for trauma is beyond the scope of this chapter, and should not be a consideration for 99% of these injuries in the acute setting. You may rarely encounter an injury that is best managed with this approach. These would include major devascularization of the second/third portions of the duodenum, destructive injury of the pancreatic head with or without duodenal injury, or injuries to the pancreas/duodenum/common bile duct that are not amenable to simpler reconstruction. Even if you identify such an injury pattern, your best option is to control bleeding and any spillage, leave adequate drainage, and disturb the anatomy as little as possible. Bring the patient back to the ICU for resuscitation and stabilization, discuss the case with your colleagues and gather your most experienced people. If the determination is that a major resection and reconstruction is the best option, then you can now proceed in a more elective setting with a stable patient (Fig. 9.9). Remember that you will not have all of the modern adjuncts immediately available for postoperative problems, such as percutaneous drainage or ERCP and stenting. If the patient is going to be evacuated to a higher level of care, then consider leaving the abdomen open for a re-exploration and evaluation at the next facility. Ensure adequate drains are placed at all anastomoses and that a secure route for nutrition is obtained, usually with a feeding jejunostomy.

In conclusion, these injuries are among the most stressful and challenging that you will encounter in a combat or disaster situation. Stick to the basic principles outlined

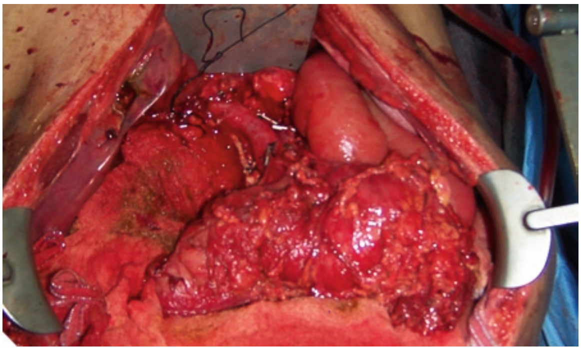

Fig. 9.9 Introperative photo of resected head of pancreas and duodenum immediately prior to reconstruction at a Combat Support Hospital. The patient underwent initial damage control surgery with no attempt at resection, and subsequently underwent a delayed Whipple procedure (48 h later) which allowed interim stabilization and operative preparations

here and *always* seek out experienced help if it is available. Wide drainage is the primary initial treatment modality for most injuries of the pancreas. Simple injuries of the duodenum can be repaired primarily but more extensive injuries may require diversion of gastric contents and options for enteral feeding. Complex repairs of the pancreas and duodenum should not be undertaken in the acute trauma setting. And remember to eat when you can, sleep when you can, and don't mess *too much* with the pancreas and duodenum.

Chapter 10
Operative Management of Renal Injuries

Carlos V.R. Brown

Deployment Experience:

Carlos V.R. Brown	Officer in Charge and Trauma Surgeon, Naval Surgical Detachment, Ramadi, Iraq, 2006–2007

BLUF Box (Bottom Line Up Front)

1. Standard evaluation of the abdomen with FAST or DPA may be unreliable in the casualty with a kidney injury due its retroperitoneal location.
2. Prior to exposing either kidney in an attempt to repair, or particularly if you expect to perform a nephrectomy, you should palpate the contralateral kidney.
3. If you encounter significant bleeding from the kidney, you can control hemorrhage by compressing the renal parenchyma in your hand.
4. The hemodynamic status of the casualty is the most important variable that affects decisions during an operation to treat a renal injury.
5. Complex renal repair or salvage is not an option in the unstable or "semi-stable" patient – you will lose the patient while trying to salvage the kidney.
6. Nephrectomy is always an option for a casualty with a severe renal injury, and should not be considered a last resort but rather a life-saving procedure.
7. Know when to not poke the skunk – *lateral* zone II retroperitoneal hematomas that are not expanding in a *stable* patient do not need to be explored (yes, even in penetrating trauma).

A chain is only as strong as its weakest link….the obvious weakest link in the severely wounded in this war (WW II) was the kidney.

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Introduction

This chapter will cover the operative management of renal injuries encountered during the care of combat trauma casualties. Renal injuries may seem daunting to the elective general surgeon not accustomed to operating in the retroperitoneum or on the genitourinary system. However, a basic understanding of management of renal injuries is essential for the combat surgeon as the kidney may be injured by any mechanism, particularly in the setting of penetrating or blast injury. You are highly unlikely to have a Urologist or Transplant Surgeon immediately available to assist you, but you can expertly manage renal trauma without them. This chapter will review indications for operation and renal exploration, operative exposure and injury evaluation, repair and resection (partial and nephrectomy) of the injured kidney, and postoperative complications.

Indications for Operation and Renal Exploration

The patient with a renal injury is rarely obvious at initial presentation. The casualty will present with abdominal trauma, either blunt or penetrating, and you must efficiently sort out whether this casualty needs an emergent laparotomy or merits further evaluation. However, like all combat casualties, hemodynamic stability is the driving force behind indications for operation. A hemodynamically unstable casualty with penetrating abdominal trauma mandates emergent exploratory laparotomy. Similarly, a hemodynamically unstable casualty who has sustained blunt or blast injury requires emergent laparotomy if the instability is attributable to the abdomen (positive focused assessment with Sonography for trauma [FAST exam] or diagnostic peritoneal aspirate [DPA]). However the retroperitoneum is not easily evaluated by FAST or DPA, thus a casualty with blunt or blast injury in whom other sources of hypotension have been ruled out and instability persists may require a laparotomy to definitively rule out an intra-abdominal or retroperitoneal source of hemorrhage.

In casualties with abdominal trauma and hemodynamic instability who are taken directly to the operating room, the presence of a renal injury will be discovered at the time of laparotomy. However, if you place a urinary catheter and see gross hematuria, then your index of suspicion for a genitourinary injury is obviously heightened. Your most likely diagnosis will be a bladder injury, but you must always assume the possibility of a major renal injury. Conversely, do not depend on gross hematuria as a clue – normal appearing urine is a common finding with even high grade renal lacerations. Like any casualty requiring laparotomy, those with a suspected renal injury should be in the supine position with both arms abducted, prepped and draped widely (chin to mid-thigh, table-to-table), and you should access the abdomen via a generous midline laparotomy from xyphoid to pubis. Upon entering the abdomen you should proceed as with any casualty with intra-abdominal injury; evacuate hemoperitoneum, stop the bleeding, control contamination, and repair injuries. A renal injury will be suspected by the presence of a Zone II (lateral to the midline) retroperitoneal hematoma. However, you should address any intraperitoneal hemorrhage before attacking a renal injury, as Gerota's fascia and the retroperitoneum provide tamponade for most renal hemorrhage. If the hematoma has ruptured or is actively bleeding through a hole in Gerota's fascia, it can usually be controlled by direct pressure with a lap sponge.

Once you have addressed the intraperitoneal bleeding you can turn your attention to the lateral retroperitoneum. You should explore the retroperitoneum in any hemodynamically unstable casualty with a Zone II hematoma, whether from blunt or penetrating trauma. After blunt trauma, you may choose to observe hemodynamically stable casualties with a Zone II hematoma as long the as the hematoma is not pulsatile and not expanding during a period of observation. If you choose not to explore a Zone II hematoma, that casualty will require postoperative imaging with a CT scan to fully determine the extent of renal injury. In general, you should explore all Zone II retroperitoneal hematomas secondary to penetrating trauma. However, you may consider not exploring the retroperitoneum if the hematoma lies in the lateral portion of Zone II (Fig. 10.1), away from renal hilar structures (artery, vein, ureter, renal calyx). This approach should be reserved for very select cases and only considered in hemodynamically stable casualties. Always have a clear idea of what you are looking for or expecting with retroperitoneal hematomas. A zone II hematoma is assumed to be either due to an injury to the renal vascular pedicle or to the renal parenchyma. If the hematoma is lateral to the renal hilum, then you can assume it represents a parenchymal injury which we know can usually be managed without surgical intervention. However, in the combat scenario you must also consider your ability to closely observe the patient postoperatively and how soon he will be placed into the evacuation chain.

In casualties with suspected intra-abdominal injury that present and remain hemodynamically stable, the presence of a renal injury will usually be discovered at the time of CT scan of the abdomen. CT scan is the definitive imaging used to evaluate renal injuries and if available obviates the need for any other diagnostic

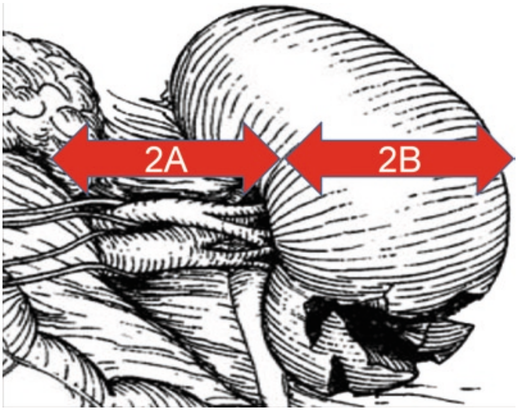

Fig. 10.1 Zone II retroperitoneal injuries can be broken down into a medial sub-zone (2A) that contains the critical vascular structures and collecting system, and a lateral (2B) sub-zone that only consists of renal parenchyma. For stable penetrating trauma patients with a non-expanding zone 2B hematoma found at laparotomy, consideration should be given to observation as opposed to mandatory exploration. Modified with permission from Master and McAninch, Urol Clin N Am 2006;33:21–31

Table 10.1 American Association for the Surgery of Trauma organ injury severity scale for renal trauma

Grade[a]	Type of injury	Description of injury
I	Contusion	Microscopic or gross hematuria, urologic studies normal
	Hematoma	Subcapsular, nonexpanding without parenchymal laceration
II	Hematoma	Nonexpanding perirenal hematoma confined to renal retroperitoneum
	Laceration	<1.0 cm parenchymal depth of renal cortex without urinary extravagation
III	Laceration	>1.0 cm parenchymal depth without collecting system rupture or urinary extravasation
IV	Laceration	Parenchymal laceration extending through renal cortex, medulla, and collecting system
	Vascular	Main renal artery or vein injury with contained hemorrhage
V	Laceration	Completely shattered kidney
	Vascular	Avulsion of renal hilum which devascularizes kidney

[a]Advance one grade for bilateral injuries up to grade III

tests such as an intravenous pyelogram (IVP). You can use the CT scan to grade renal injuries according to the American Association for the Surgery of Trauma organ injury severity scale for renal trauma (Table 10.1). You can use the grade of injury seen on CT scan to determine need for operative management of the renal injury. In general, you may manage grade I and II injuries nonoperatively and most will heal without consequence. You can also treat grade III and IV lacerations without operation. However, if other intraperitoneal injuries seen on CT scan require operative intervention, you should explore the grade III/IV laceration at the time of laparotomy. If you discover a renal vascular injury (grade IV or V) or a grade V laceration (shattered kidney) on CT scan, you should take the casualty for laparotomy and renal exploration. You usually will not have access to advanced interventional radiologic support or even adjuncts such as cystoscopy and stent placement. Take this into consideration when applying the civilian paradigm of nonoperative management of these injuries.

Exposure and Injury Evaluation

During the initial laparotomy your exposure to the kidney will be greatly facilitated by placing a self-retaining retractor such as a Balfour or preferably a Bookwalter. Surgical equipment may vary significantly depending on your unit and supply chain (particularly in a far forward detachment), so I encourage you to open your surgical instruments and retractors to familiarize yourself before your first operation. Prior to exposing either kidney in an attempt to repair, or particularly if you expect to perform a nephrectomy, you should palpate the contralateral kidney. If you feel a normal kidney on the unaffected side, you can feel comfortable in performing a nephrectomy on the injured side if needed, without fear of making the casualty dialysis-dependent. In the unusual case that you palpate an abnormal kidney (absent, atrophic, polycystic) on the unaffected side you may consider performing an on-table IVP to determine if the abnormal kidney is functional. However, trying to routinely perform an on-table IVP in order to evaluate the function of the uninjured kidney is unnecessary, technically difficult, often inadequate, and most importantly time consuming. Ditto for the oft-touted “one-shot IVP” in the Emergency Department for penetrating trauma patients. Don’t waste time and effort on these mostly useless studies.

Once you have palpated a normal contralateral kidney and are ready to approach the injured side, you may use one of two approaches for exposure of the kidneys. You may either (1) obtain initial renal vascular control followed by renal exploration or (2) initially explore the kidney and obtain renal vascular control after complete mobilization of the kidney. Both approaches have pros and cons and should be individualized based on the casualty and the surgeon’s experience and expertise. In general, approach no. 1 should be considered the preferable “elective” approach in a stable patient without ongoing hemorrhage and approach no. 2 is the preferred approach when time is of the essence. Obtaining initial vascular control has the benefit of securing definitive vascular control prior to exposing the injured kidney, allowing you to secure inflow and outflow if exsanguinating hemorrhage is encountered from the kidney. Figures 10.2 and 10.3 demonstrate the maneuvers and anatomy to obtain renal vascular control. However, there are several downsides to obtaining vascular control prior to renal exposure. First, a small minority of renal injuries will require vascular control prior to repair, making this maneuver unnecessary in most cases. Second, obtaining vascular control in the midline can be technically challenging, particularly in the setting of a large retroperitoneal hematoma and for the surgeon inexperienced in vascular or urological surgery. Finally and most importantly, obtaining initial vascular control is definitely time consuming, even in experienced hands, and can delay definitive renal repair or a potentially life-saving nephrectomy. For these reasons, while managing renal injuries in the setting of combat surgery, you

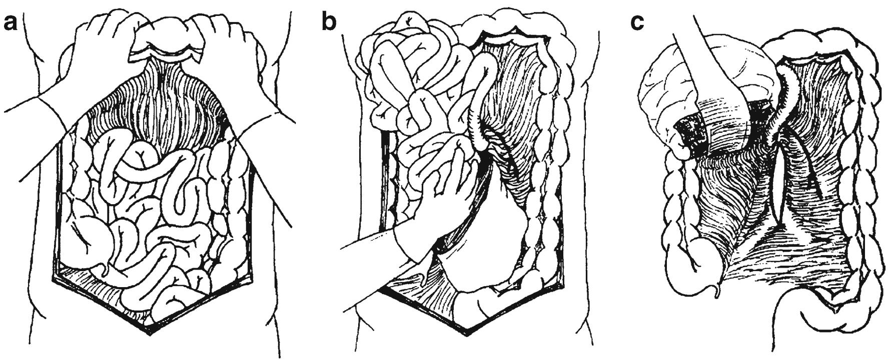

Fig. 10.2 Exposure for proximal renal vascular control is obtained by superior retraction of the transverse colon (**a**), evisceration and retraction of the small bowel to the *right upper* quadrant (**b**), and opening the retroperitoneum longitudinally along the aorta (**c**) (reprinted with permission from Master and McAninch, Urol Clin N Am 2006;33:21–31)

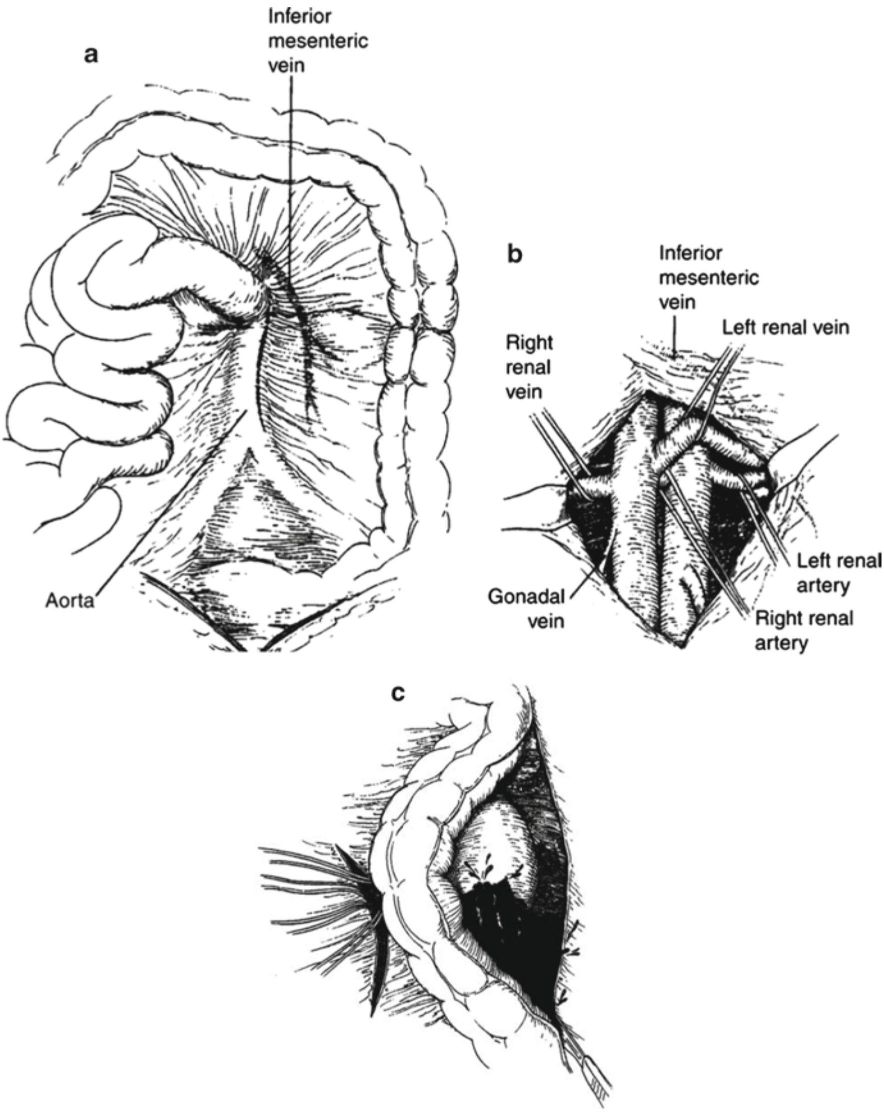

Fig. 10.3 The retroperitoneum is opened longitudinally directly over the aorta (**a**) which should first expose the left renal vein. Both renal veins (anterior) and arteries (posterior) can now be identified and controlled with vessel loops (**b**). The colon can now be mobilized medially and Gerota's fascia opened to explore the kidney (**c**) (reprinted with permission from Master and McAninch, Urol Clin N Am 2006;33:21–31)

should first efficiently expose the injured kidney and then obtain vascular control of the renal pedicle if necessary (Fig. 10.4).

The kidney is exposed in a similar fashion on the right and left side. You mobilize the right or left colon medially by taking down the white line of Toldt, a maneuver

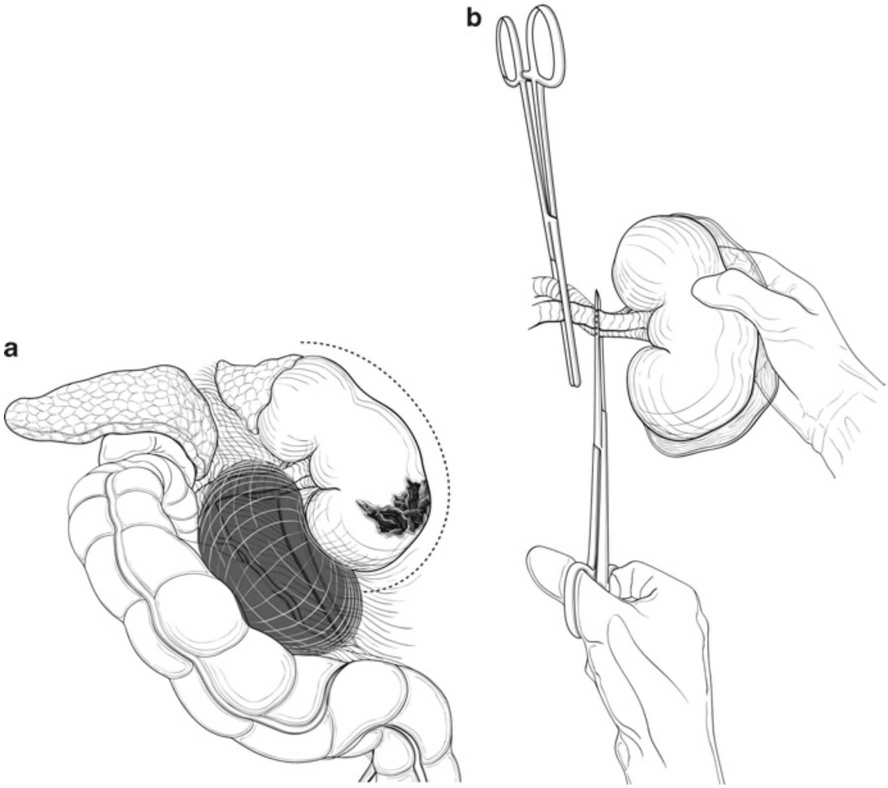

Fig. 10.4 Rapid renal mobilization is obtained by opening Gerota's fascia on the lateral border of the kidney and lifting the kidney out of the retroperitoneum (**a**). It will now be suspended by only the renal vessels and the ureter, which can be clamped and divided if nephrectomy is required (**b**)

that is facilitated by the retroperitoneal hematoma. The majority of this mobilization can be done rapidly with your hand and aggressive blunt dissection, retracting the colon and colonic mesentery to the midline. After mobilizing either colon medially, sharply open Gerota's fascia widely in a longitudinal fashion *lateral* to the kidney. Once you have entered Gerota's fascia, you should be able to bluntly and easily mobilize the entire kidney and renal hilum into the operative field allowing you to completely inspect the kidney and vasculature structures for the extent of injury. Grab the kidney with your entire hand and lift it up and out of the retroperitoneum. There will usually be superior and inferior fibrous bands that can be rapidly divided with electrocautery allowing full mobilization. The kidney should now be suspended in the midline, attached only by the renal hilum containing the artery, vein, and ureter. If you encounter significant bleeding from the kidney, you can control hemorrhage by compressing the renal parenchyma in your hand. While you (or your assistant) compress the kidney you can obtain control of the renal vasculature manually or by placing a vascular clamp across the renal artery and vein en-masse.

Now you can evaluate the extent of injury to the parenchyma or vasculature and plan your surgical approach to repair or resection.

Repair and Resection

Several factors need to be considered when formulating an operative plan for managing renal injuries. The hemodynamic status of the casualty is the most important variable that affects decisions during an operation to treat a renal injury. A hemodynamically stable casualty may allow you to perform a more complex (and more time consuming) repair of an injured kidney or renal vasculature if necessary. On the contrary, if you are faced with a hypotensive casualty with a renal injury, you should make no attempt at a complicated repair, and the only reasonable options are a quick and simple repair of lower grade injuries or a nephrectomy for more severe injuries. A critical and lethal error may occur when performing a complex renal repair in a hemodynamically unstable casualty with ongoing hemorrhage, causing you to lose the casualty while trying to salvage the kidney. Finally, palpating a normal kidney on the uninjured (contralateral) side should make you comfortable in performing any procedure necessary to address renal hemorrhage, including a nephrectomy.

Beware the curse of too many consultants! If you happen to have additional surgical sub-specialty expertise available for consultation, then use them liberally as needed. A Urologist or Vascular Surgeon can certainly add a degree of expertise and familiarity with exposure and advanced techniques beyond the scope of most General or Trauma Surgeons. This is particularly true if you are contemplating renal preservation with some type of complex parenchymal or vascular repair. However, remember that they will usually also bring a tendency toward thinking in terms of “elective” surgery and may not fully grasp the impact of prolonging the operation or the extent and degree of other injuries that need to be addressed. You are the one who has the big picture and a deep understanding of emergency trauma surgery, so stay in control and make sure the operation stays on track.

Parenchymal Injuries

Many renal parenchymal injuries you encounter during exploration of the injured kidney can be managed with minimal intervention. Any contusion or subcapsular hematoma should be left alone. If you encounter parenchymal lacerations not involving the urinary collecting system you may manage them by sharply debriding devitalized tissue, obtaining hemostasis with cautery or suture ligature as needed, and reapproximating the renal capsule if possible. Suture ligatures and reapproximation of the capsule should be performed with absorbable, monofilament suture in order to avoid future renal calculi formation. Pledgets should be used if the tissue is friable or your sutures are unable to be tied securely without tearing. If no standard pledgets are available, you

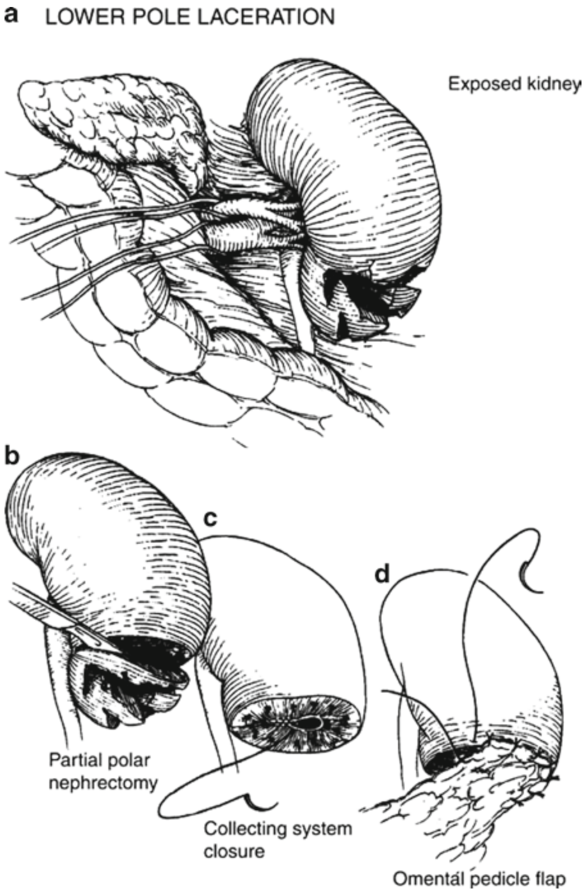

Fig. 10.5 (**a**) Exposure of a lower pole renal laceration, (**b**) Sharp debridement of the injured segment, (**c**) Water-tight closure of the collecting system with absorbable suture, and (**d**) Coverage with an omental pedicle flap (reprinted with permission from Master and McAninch, Urol Clin N Am 2006;33:21–31)

can easily make them by excising a piece of peritoneum and cutting it into small squares. If you cannot easily reapproximate the renal capsule without tension, you can handle the raw parenchymal surface by applying tissue glue or a topical hemostatic agent, or by suturing an omental flap to the edge of renal capsule (Fig. 10.5).

If the renal injury involves the collecting system you should attempt to perform a watertight repair with chromic suture to avoid a postoperative urine leak. If you have any question regarding violation of the urinary collecting system, you may inject a few cc's of methylene blue into the renal pelvis and observe the parenchyma for extravasation of dye. Once you have completed repair of the urinary system you can manage the parenchymal defect as detailed previously. If the injury involves the superior or inferior pole of the kidney you may perform a partial nephrectomy of either pole and manage the urinary system and parenchyma as described. Following any renal repair, with or without obvious injury to the urinary system, you should leave a closed suction drain in a dependent portion of the renal fossa to drain any postoperative urine leak.

Vascular Injuries

Renal vascular injuries are much less common than parenchymal injures, but as a combat surgeon you are more likely to encounter this difficult injury than in civilian practice due to the high rate of penetrating trauma seen by military surgeons. Renal vascular injuries may involve the renal artery, renal vein, or present as a combination injury. Management of renal artery injuries follows the same principles as other arterial injuries: proximal and distal control of the injured vessel, thrombectomy, debridement of devitalized tissue, followed by definitive repair.

For arterial injuries you should obtain proximal and distal control of the injured renal artery after mobilization of the kidney as described above. After mobilization, you can control bleeding from an injured artery manually or with Debakey forceps. A few anatomic points to keep in mind; the renal veins maintain an anterior position to the renal arteries bilaterally, and may need to be mobilized to clearly visualize the arteries. In addition, the left renal vein will be longer than the right, while the right renal artery will be longer then the left due to their relationship to the IVC and aorta respectively. To access the right sided vessels, open the retroperitoneum longitudinally along the right border of the vena cava as you retract the kidney laterally. The right renal vein should be the first large branch you encounter, and the artery can be found posterior to the vein. On the left, exposure of the renal vessels requires mobilization of the ligament of Treitz. The renal vein can be identified by division of the ligament of Treitz with retraction of the duodenum superiorly, or by identifying the gonadal vein inferiorly and following it to its junction with the renal vein. Again, the artery is located posterior to the vein. You should encircle the artery in a vessel loop and occlude it with a fine vascular clamp; consider using an angled Debakey clamp or bulldog. Do not forget that multiple or accessory renal arteries are commonly encountered, but there should be a dominant vessel to the organ.

Once you have obtained proximal and distal control of the artery you should check for antegrade and retrograde bleeding and pass an embolectomy catheter as needed. Though you will not always need to pass a catheter into the proximal artery due to brisk bleeding and lower likelihood of retained clot, you should always pass an embolectomy catheter in the distal end of the artery to ensure no thrombus is present. Now you may debride any devitalized tissue from the edges of the injured artery. You may repair an arterial laceration or incomplete transection with interrupted 5-0 prolene sutures. If the artery is completely transected, you can perform a primary (tension free) reanastomosis or place an interposition graft with reversed saphenous vein. If you are not experienced in performing a vascular anastomosis, you should place a temporary arterial shunt with plans for a definitive reconstruction as soon as possible at a higher echelon of care. If you encounter an injury to the renal vein you may perform a venorrhaphy if there is a small laceration and the resultant stenosis will be less than 50% (Fig. 10.6). If the injury to the vein is significant you should ligate it and not attempt any complex venous reconstructions. Remember that on the left side, ligating the vein at the junction with the IVC is preferable to ligating it closer to the kidney, as this may allow drainage via the adrenal and gonadal collaterals.

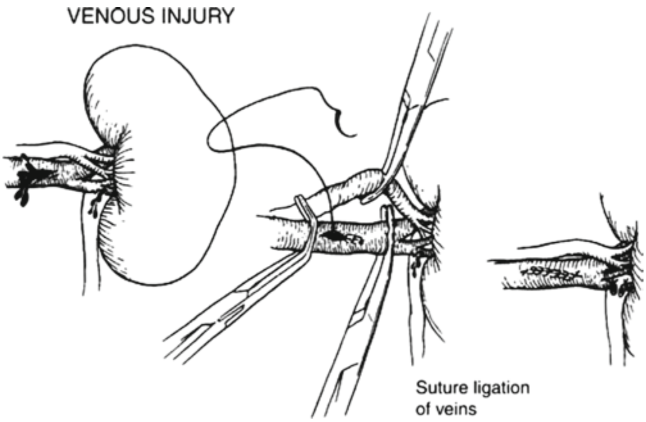

Fig. 10.6 Left renal vein laceration (*left panel*) managed with proximal and distal control followed by lateral venorrhaphy (*middle*). Small bleeding veins are suture ligated and the repair is completed (*right*) (reprinted with permission from Master and McAninch, Urol Clin N Am 2006;33:21–31)

Nephrectomy

Nephrectomy is always an option for a casualty with a complex renal injury, and should not be considered a last resort but rather a life-saving procedure. Indications for nephrectomy include hemodynamic instability, ongoing hemorrhage or need for transfusion (from the kidney or any other source), unreconstructable renal injury including vascular, parenchymal, or urinary collecting system, complex renal injury requiring more operative time to repair than the casualty will tolerate, and severe associated intra-abdominal injury. In order to perform a nephrectomy you should manually elevate the kidney as previously described, allowing you to visualize the renal artery and vein. If you have time and exposure, independently dissect and expose the artery and vein and divide each between clamps, suture ligating the proximal end. If not, clamp the hilum en masse and suture ligate the vessels as a bundle or fire a linear stapler with a vascular load across the hilum. Now the only attachment of the kidney should the ureter, which is identified and divided after simple ligation.

Complications

As with any operation, complications such as bleeding and infection (including abscess) may occur in the postoperative period following surgery for an injured kidney. However, several complications specific to renal injuries merit further discussion. Some decline in renal function is usually seen, and a doubling of the serum creatinine can be expected in the first several days. With a normal functioning contralateral kidney, this should return to baseline or slightly above baseline. Urinary leak is the most common complication you will encounter after an operation for renal injury. As mentioned previously, you should leave a closed suction drain after any renal repair and urine emanating from the drain confirms the diagnosis of a urine leak. The majority of urine leaks will heal spontaneously within a few days and require no specific intervention. If the leak persists after several weeks the casualty may need a ureteral stent or percutaneous nephrostomy to aid in sealing the leak. If you identify an undrained collection of urine (urinoma) on postoperative imaging you should drain the urinoma percutaneously and manage the same way as a urine leak. If you have performed a complex renal repair or reconstruction, the casualty may be at risk to develop hypertension in the late postoperative period. The casualty should be educated as to the risk of long term blood pressure elevation and should receive lifelong screening for hypertension.

In conclusion, combat surgeons are much more likely to be faced with managing significant renal or renal vascular injuries in the operating room than their civilian counterparts. The key to success lies in familiarizing yourself with the local anatomy before you have to deal with it in the operating room in a bloody and distorted field, and applying the main principles of emergent trauma surgery. Keep it simple, stay focused on the whole patient and not the individual organ, communicate with and lead your team, and always have a backup plan or bail-out option in case of disaster.

Chapter 11
Major Abdominal Vascular Trauma

Niten Singh

Deployment Experience:

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Vascular Surgeon, 28th Combat Support Hospital, Baghdad, Iraq, 2006–2007

BLUF Box (Bottom Line Up Front)

1. Proceed directly to the operating room if there is suspected abdominal vascular trauma in an unstable patient.
2. The best imaging of abdominal vascular injury is with your eyes – don't delay for unnecessary imaging.
3. The first principle of damage control surgery is control hemorrhage – don't worry about the bowel if the iliac artery is bleeding.
4. Permissive hypotension is tolerated well and often makes arterial bleeding easier to control.
5. Packing of solid organ injuries is useful; however packing of arteries that are partially transected is often ineffective.
6. Finger control of bleeding is better than packing and blind clamping.
7. If a major vascular injury is suspected from blunt injury, ensure that adequate IV access is obtained and blood is in the room and hanging prior to opening the abdomen, as loss of the tamponade effect will result in expected hypotension.
8. Know your exposures and visceral rotation maneuvers in the abdomen.
9. Suction is not a method of vascular control and can "suck" the life out of a patient if used continuously near an arterial injury. Don't be a sucker.
10. Preop you should be thinking about how to get proximal and distal control. Intraop you should be thinking about inflow, outflow, and what conduit to use.

It is a good plan in fresh wounds, except those in the abdomen, to allow a lot of blood to escape.

Hippocrates (460–377 BC)

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Introduction

The increasing popularity of non-operative management for trauma patients is predicated on excellent imaging, the ability to percutaneously control bleeding and repair blood vessels, and the resources to closely monitor patients in a well-stocked intensive care unit. For example, whereas just a few years ago a patient with a gunshot wound to the flank that was hemodynamically stable would likely proceed directly to the operating room for an exploratory laparotomy, it is now acceptable to observe this patient if triple phase CT scan is normal. Unfortunately, this is not the situation in a combat setting. Although you may have a CT scanner, it may overheat; you may have a C-arm and feel comfortable performing endovascular procedures, but nobody else around you does; and you will have an ICU that is efficient but can easily be overwhelmed by a mass casualty event. It is therefore incumbent upon you and your operating team to be prepared to deal with whatever is brought to the ER, because if you are in a combat support hospital YOU are the highest level of care in country. The goal of this chapter is to assist you with major abdominal vascular trauma and pass on these lessons learned (often the hard way) from combat surgery.

The Basics in the ER

Sometimes forgotten in the chaos of multiple unstable patients in the ER is the basic premise that the majority of patients in a combat scenario are best served in the operating room. This concept is in direct opposition to the stable patients in a car accident back home who can often spend the night in the ER or CT scanner to work up their blunt trauma. Many times patients will arrive intubated in the ER and/or not be capable of conveying the mechanism of injury or a chief complaint. One of the easiest ways to discern whether you are heading to the OR is the mechanism of injury – *blunt or penetrating*. Patients who have a large penetrating abdominal wound with intestines hanging out are heading to the OR. Those with blunt injuries, a negative FAST exam, and are conversant can observed or imaged as needed. Patients who are hemodynamically unstable and have penetrating abdominal injury should be taken to the operating room. Blunt injury patients that are unstable, neurologically intact and have a positive FAST should also be immediately explored. If a patient (particularly one with penetrating trauma) loses vitals in front of you an ER thoracotomy should be performed.

A few points to remember in the basic work-up of combat casualties: (1) a chest X-ray rarely takes any time, and allowing the support personnel to obtain basic blood work is also not time consuming; (2) if you can obtain a pulse exam (hard to do even with stethoscope Doppler probes), get one; (3) a central line should be placed in the jugular or subclavian vein rather than the femoral vein if abdominal vascular injury is suspected.

In the OR: Getting Started

It is often easier to drape a patient if both of their lower extremities are prepped circumferentially. It may sound cumbersome, but with the number of personnel in the OR it is not difficult. Placing two down sheets, a groin towel, and wrapping both feet in towels allows easy access to both legs if greater saphenous vein is needed, and can allow another team to do the harvest without crowding the abdominal team. The proximal extent of the prep should include the chest to the clavicles, or the chin if thoracic wounds are present. A laparotomy sheet or two split sheets can be centered over the abdomen and cover the prepped area. If vein harvest is required from the legs or proximal control in the chest is needed, the overlying drape can be cut and the area easily accessed. The prep is very quickly performed with betadine paint alone and/or with single applicator prep. During this time you should focus your thoughts on your plan, take a moment to collect yourself, and make sure the patient has blood products and adequate vascular access.

In the OR: Injuries Encountered

Upon performing the laparotomy, any number of scenarios can occur but most can generally be grouped into one of the following situations:

1. Free blood with isolated major vascular injury **(rare)**
2. Free blood with succus and hollow viscus injury or solid organ injury **(more common)**
3. Retroperitoneal hematomas and no major intra-abdominal injury
4. Retroperitoneal hematoma and intra-abdominal viscus injury
5. Pelvic hematoma

The retroperitoneum is divided into three zones in the abdominal cavity (Fig. 11.1). Remember that the zones are all about major blood vessels, so if you see a large hematoma you generally know what vessel(s) you are worried about. As soon as you have identified the zone of injury, your next step is to rule in or rule out an injury to the primary LARGE vessels in that zone. *Zone 1* encompasses the entire central region of the retroperitoneum and is subdivided into *supramesocolic* and *inframesocolic*. This zone contains the aorta, IVC, celiac, SMA and IMA and is in close proximity to the pancreas and duodenum. *Zone 2* is the left and right portions of the retroperitoneum and contains the left and right kidneys and the renal vessels. *Zone 3* is the pelvic portion of the retroperitoneum and contains the iliac and femoral vessels. The main purpose of this classification is to trigger an automatic plan based on the retroperitoneal zone that is found to have hematoma during laparotomy. Many times the hematoma will be crossing zones, but it is usually clear which zone it originates from. It is also not unheard of in combat injuries, particularly explosive mechanisms with multiple fragments, to have vascular injuries in more than one zone. A few generalities regarding hematomas encountered in the retroperitoneum are listed below:

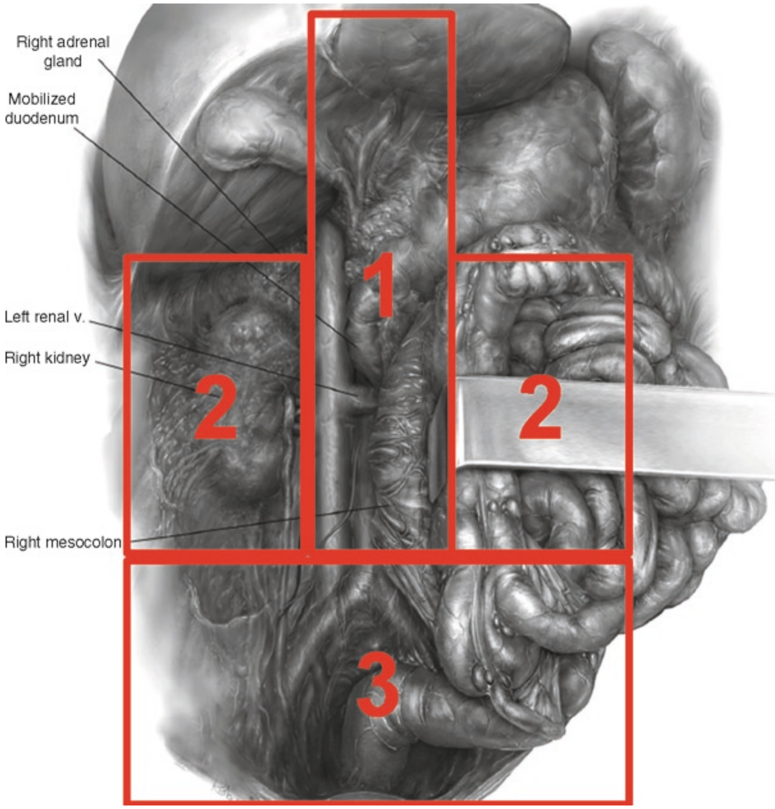

Fig. 11.1 Zones of the retroperitoneum. *1* zone 1, central retroperitoneum which contains the vena cava, aorta, and their major branches. *2* zone 2, lateral (or renal) space which contains the renal vessels and kidneys. *3* zone 3, pelvis which contains the iliac artery and vein system. (Modified with permission from Cook et al., Operative Techniques in General Surgery 2008;10:154–163)

Hematomas in Different Zones

1. For **blunt** trauma **ONLY** do not open zone 2 or 3 hematomas and retro-hepatic hematomas unless expanding or pulsatile, or patient instability with no other source.
2. **OPEN and explore** all penetrating hematomas except for the retro-hepatic hematoma (Unless it is ruptured, pulsatile, or rapidly expanding).
3. There are exceptions to these rules (discussed below), but they are unusual.

Although this is a fairly simplistic algorithm, since many of the injuries you will encounter are penetrating you ***WILL*** explore these hematomas. Often these injuries are not going to “sneak up on you”; they will likely be filling the abdomen with blood.

The only scenario in penetrating trauma where you may want to delay opening a hematoma is in the patient with multiple injuries who is unstable. If the size and extent of the hematoma does not explain the patient’s unstable physiology, you may want to leave that hematoma alone initially and look for the hemorrhage source that is really killing the patient. These other sources could include previously quiescent extremity hemorrhage (blood loss “under the drapes”), blood loss into other cavities (such as the chest), scalp hemorrhage, or cardiac tamponade.

In the OR: Operative Technique

Most penetrating abdominal vascular injuries are noted in conjunction with hollow viscus injury. Therefore, if there is massive blood and succus encountered, the initial tasks are packing the four quadrants and identifying the vascular injury and controlling it with finger pressure or clamping after gaining appropriate proximal and distal control. Often a patient in shock can be temporized with packing and this allows you time to identify viscus injuries and quickly staple injured bowel segments. The packs can be sequentially removed and the vascular injury approached.

Zone 1 Supramesocolic Injuries

If a Zone 1 supramesocolic injury or hematoma is encountered, a left medial visceral rotation should be performed (Fig. 11.2). This maneuver allows visualization of the entire abdominal aorta from the hiatus to the bifurcation. The exposure involves mobilization of the left colon, dividing the lienosplenic ligament, and bluntly elevating the left colon, left kidney (optional), pancreas, and stomach. Once the peritoneum along the line of Toldt is opened, the rest of this maneuver can be rapidly done with blunt hand dissection and bovie. Sweep everything medially until you feel

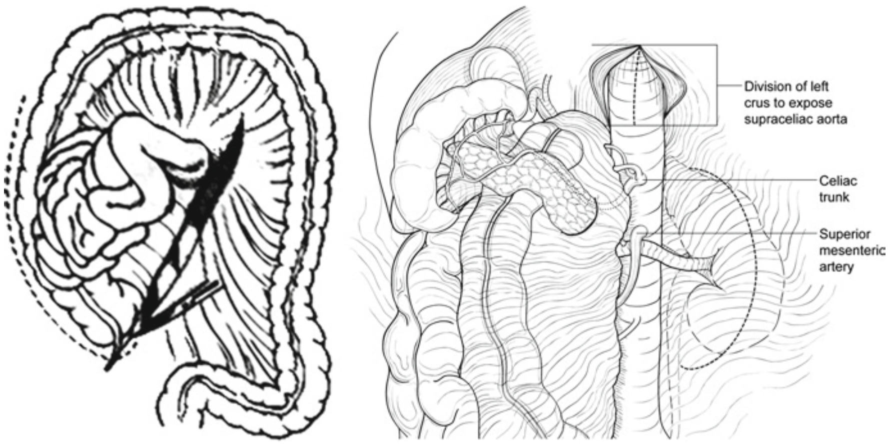

Fig. 11.2 Left medial visceral rotation. Open the lateral attachments of the descending colon (*white line* of Toldt) and spleen sharply and you can then bluntly dissect these structures anteriorly and medially (roll them toward you) until you come to the aorta and spine

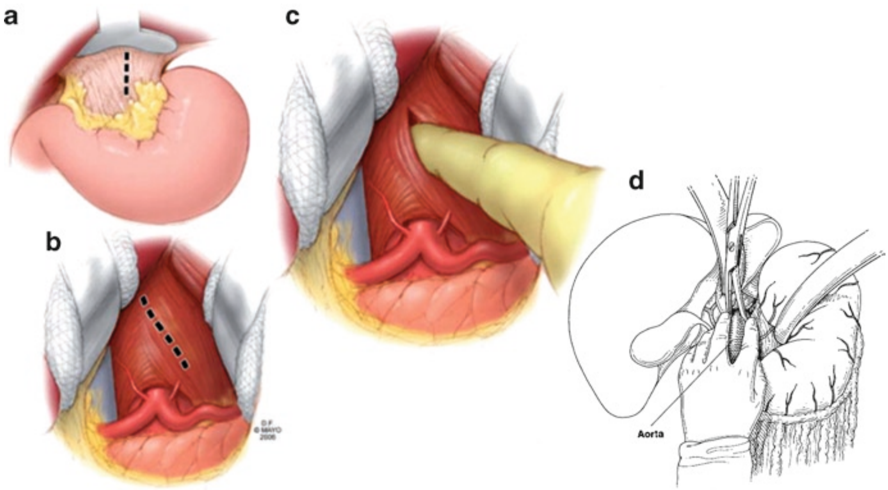

Fig. 11.3 Supraceliac control is obtained by opening the gastrohepatic ligament (**a**), lateral retraction of the stomach and left lobe of the liver, and division of the overlying diaphragmatic crural fibers (**b**). Finger dissection (**c**) is helpful to establish a circumferential plane for clamp placement (**d**). (Reprinted with permission from Lin et al., Surgical Clinics of North America 2000;80:417–433)

the vertebral bodies. Once the viscera are all rotated up off the retroperitoneum, there is usually a thin plane of tissue along the side of the aorta which must be opened to directly expose aortic adventitia and aortic branches. If there is active bleeding from this area when entering the abdomen or opening a hematoma, the aorta can be blindly compressed by your assistant at the aortic hiatus with a hand or the blunt end of a large retractor. To apply a supraceliac cross-clamp the gastrohepatic ligament is divided, the left crus of the diaphragm is bluntly dissected and the aorta is identified at the hiatus (Fig. 11.3). A *key point* is it is easier to identify the aorta if the esophagus has an NGT in it, and often it is *not* easy to clamp this area, particularly in obese patients. If you are uncomfortable with this vascular control technique than an anterolateral thoracotomy is still an option to obtain proximal control. Always **remember** to reposition the clamp to a lower position when feasible if a supraceliac cross-clamp is in place to limit visceral ischemic time.

Specific Zone I Supramesocolic Vascular Injuries

Aorta – Small injuries to the aorta are debrided and repaired primarily with 3-0 and 4-0 prolene sutures. If the aorta is significantly damaged, replacing it with a 12–14 mm graft is preferable as there is no vein option for this size. A rifampin soaked graft may offer some resistance to infection. A simple way to do this is to always keep 1,200 mg of rifampin in the OR (two 600 mg tablets that can be crushed on the back table and placed in 50 cc of saline for 10–20 min).

Celiac artery and its branches – All branches of the celiac artery (left gastric, splenic and common hepatic) can be ligated. The common hepatic should be ligated proximal to the gastroduodenal artery or repaired if possible.

SMA/SMV – SMA injuries should be repaired primarily or with an interposition graft. Usually a reversed greater saphenous vein graft is adequate in this situation using 5-0 or 6-0 prolene suture. Take care that the graft does not kink when the bowel is laid back in anatomic position. Omentum should be placed around the suture line. The pancreas and duodenum are commonly injured structures around this area and if there is a noted injury the vein graft should be taken off the infrarenal aorta to avoid the pancreatic injury site that can be prone to leaks. The SMV can be repaired with lateral venorrhaphy but if complex it can be ligated. If ligation is performed than aggressive fluid resuscitation should take place because patients will have mesenteric engorgement and systemic hypovolemia. **Always plan a second look laparotomy if you have messed with the SMA/SMV to evaluate for compromised bowel or graft failure**.

Zone 1 Inframesocolic Injuries

Exposure is via the same exposure for abdominal aneurysm repair. This involves retracting the transverse colon cephalad and the small bowel to the RUQ. The upper extent of the exposure is the left renal vein (see Fig. 10.2). As opposed to the suprarenal aorta the infrarenal aorta can be ligated and extra-anatomic repair can be performed if there is excessive contamination.

Specific Zone I Inframesocolic Vascular Injuries

Aorta – Exposure is as described above. The same principles apply for the repair or replacement as described in the supramesocolic aorta. Temporary shunting with 24–32 French (8–10 mm) chest tube is often discussed but rarely performed. If you have time to clamp and repair – do it. Remember that if you find one hole, you should always look for a second hole, particularly on the back wall of the vessel.

IVC – exposure to the IVC is via a right medial visceral rotation which involves an extended Kocher maneuver with mobilization of the right colon (Fig. 11.4). For a simple anterior laceration or branch avulsion, a side-biting clamp can obtain control for repair while maintaining luminal flow (Fig. 11.5a). However, this is often initially impossible in a bloody field and compression with sponge sticks is a great method for control and repair with 3-0 or 4-0 prolene (Fig. 11.5b). Remember that just like the bowel, if you have one hole you should make sure you don't have another hole. Look for a posterior injury (through and through). These are often difficult to mobilize, so extend your anterior venotomy to repair the posterior laceration from the inside (Fig. 11.6). When repair is not straightforward and the patient is unstable, ligation of the infrarenal vena cava CAN be performed. If you ligate the suprarenal IVC, pay close attention to the postop renal function as it MAY deteriorate (it often will not).

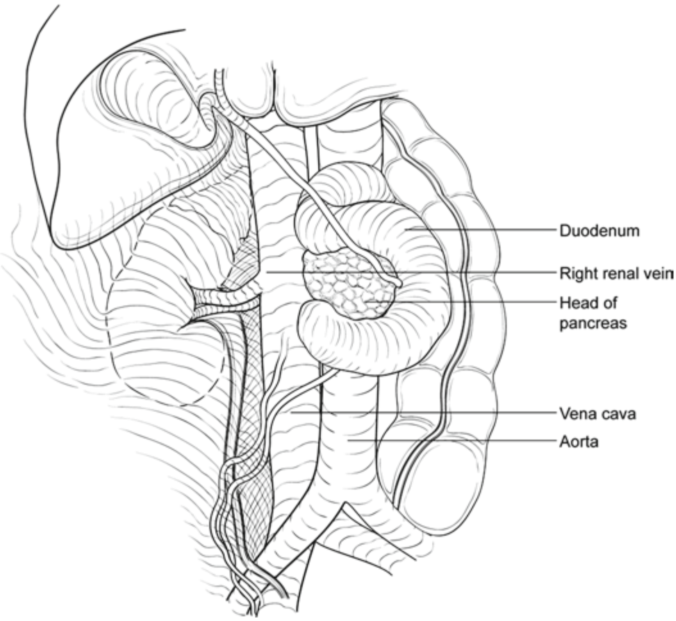

Fig. 11.4 Right medial visceral rotation achieves full exposure of the duodenum, head of pancreas, infrahepatic vena cava, and right kidney

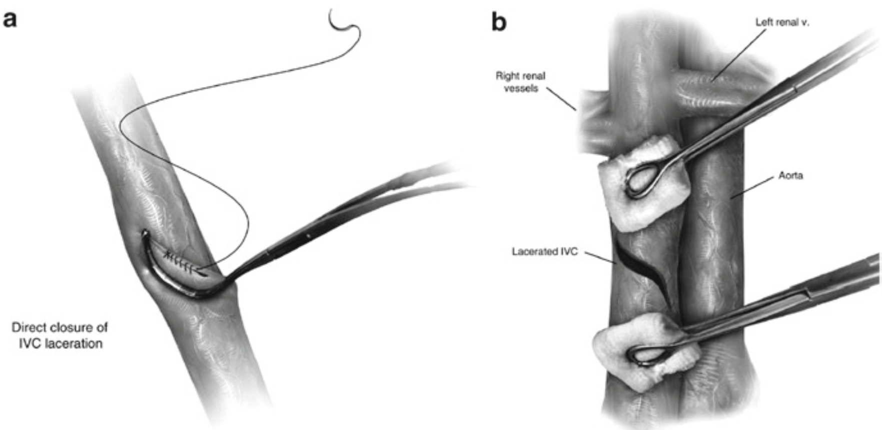

Fig. 11.5 Control and repair of an anterior vena cava laceration can be accomplished with a side-biting clamp and a running suture repair (**a**) or with two sponge sticks providing proximal and distal compression (**b**). (Reprinted with permission from Cook et al., Operative Techniques in General Surgery 2008;10:154–163)

The lower extremities should be wrapped and elevated; reconstruction can be performed at a later time. Ligation of the suprarenal IVC is associated with a high mortality but it is preferable to extended attempts at repair in an unstable patient.

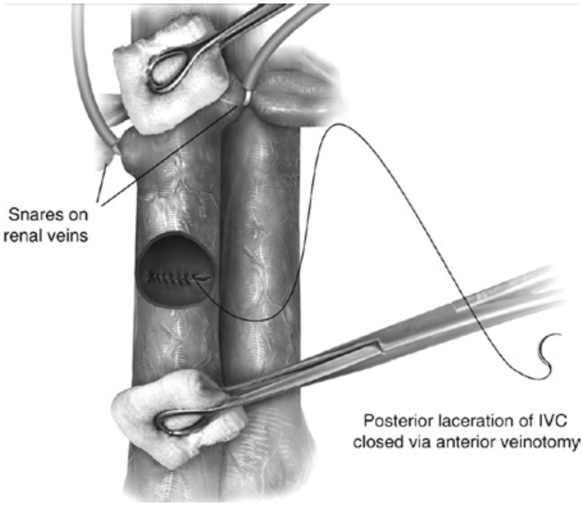

Fig. 11.6 Repair of a posterior vena cava laceration through an anterior venotomy and sponge stick control. (Reprinted with permission from Cook et al., Operative Techniques in General Surgery 2008;10:154–163)

Zone 2 Vascular Injuries

Patients with zone 2 hematomas from blunt trauma that are expanding and pulsatile should be explored, leave stable hematomas alone. The hard and fast rule taught in residency is that ALL zone 2 hematomas from penetrating trauma should be explored. This is a good general principle, but there are some specific situations where you may be better off leaving them alone even if the mechanism is penetrating. If the hematoma is clearly lateral to the renal hilum and is non-expanding, then this is either a soft tissue injury or a renal parenchymal injury. There is no reason to treat these differently than blunt injuries, and exploring them will only increase your chances of stirring up bleeding and possibly having to do a nephrectomy. For the majority of zone II penetrating hematomas that DO require operative exploration, they are best approached via right or left medial visceral rotation as described above (also see Chap. 10 on renal injuries). Lateral arteriorrhaphy of the renal artery can be performed with 5-0 and 6-0 prolene. Interposition saphenous vein grafting can be employed in stable situations. With regard to the renal veins, if the right renal vein must be ligated nephrectomy is usually required since there is no collateral drainage. The left renal vein can be safely ligated distally (close to the vena cava) as long as the adrenal, lumbar, gonadal veins are intact to provide collateral drainage for the left kidney.

Zone 3 Vascular Injuries

Associated injury of the bowel and urogenital structures often accompany injuries to the pelvic (iliac) vessels, complicating your decisions regarding repair. Exposure of the more distal vessels is often difficult, particularly for the vein injuries since they are located deep to the arteries (Fig. 11.7). In blunt trauma, hematomas should not be opened except for the caveats listed above. The focus in combat trauma is on penetrating trauma in the pelvis. With arterial trauma, if there is not complete transection these injuries can be associated with massive blood loss. Conversely, completely transected vessels tends to spasm and retract, and especially in hypotensive patients can be identified and clamped. Exposure of the distal aorta and iliac vessels is obtained as shown in Fig. 11.8. Remember that a good first move may be to clamp the distal aorta and/or vena cava, and then proceed with iliac exploration. Ligation of the internal iliac arteries is tolerated as there are extensive collateral pathways, but it is preferable to not ligate both iliac arteries. Conversely, ligation of the common iliac and/or external iliac artery is associated with a high rate of limb loss; therefore, repair or shunting of these injuries should always be attempted. Lateral arteriorrhaphy should be utilized for small injuries to the iliac arteries, whereas interposition grafting can be performed for larger injuries using an 8 mm Rifampin-soaked Dacron graft. A significant proximal injury or avulsion can be reimplanted at a lower level after some mobilization (Fig. 11.9). If you do not have vascular graft material or have massive contamination, then another option for an

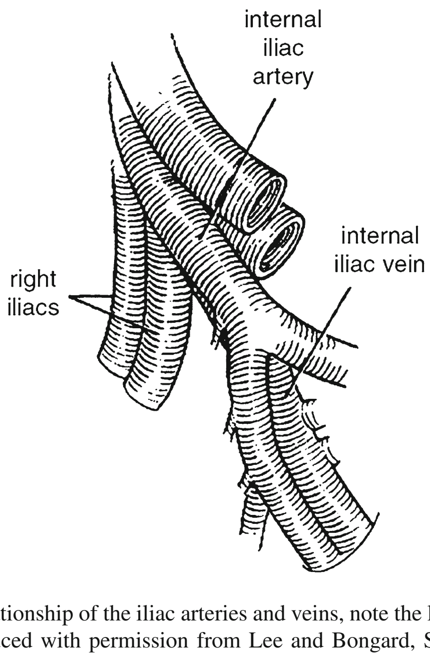

Fig. 11.7 Anatomic relationship of the iliac arteries and veins, note the location of the veins deep to the arteries. (Reproduced with permission from Lee and Bongard, Surgical Clinics of North America 2002;82:21–48)

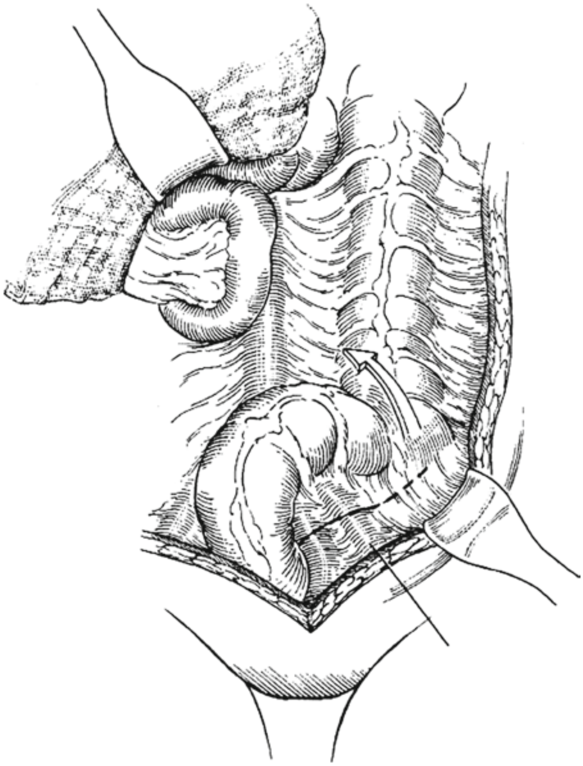

Fig. 11.8 Exposure of the distal aorta and iliac vessels. The small bowel is retracted to the right upper quadrant and the lateral attachments of the sigmoid colon are divided (*dotted line*) to obtain distal iliac exposure. (Reproduced with permission from Lee and Bongard, Surgical Clinics of North America 2002;82:21–48)

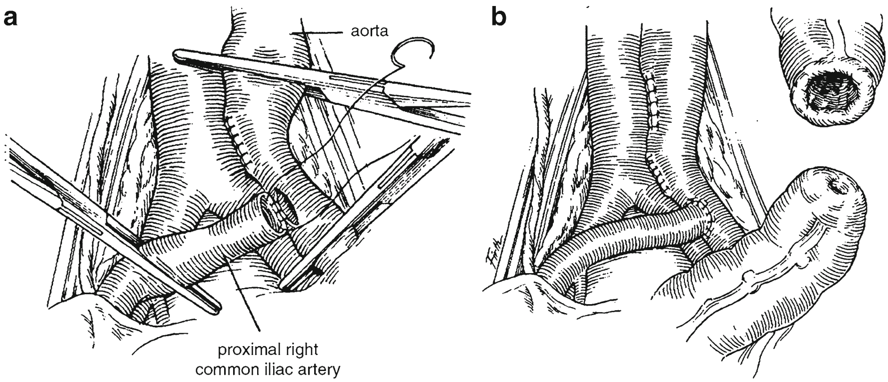

Fig. 11.9 A proximal common iliac artery injury or avulsion can be repaired by oversewing the defect and creating a new anastomosis more distal on the contralateral common iliac (**a**). This effectively creates a new and lower common iliac bifurcation (**b**) and is particularly useful in avoiding prosthetic in the setting of bowel injury (colostomy shown) or other contamination. (Reproduced with permission from Lee and Bongard, Surgical Clinics of North America 2002;82:21–48)

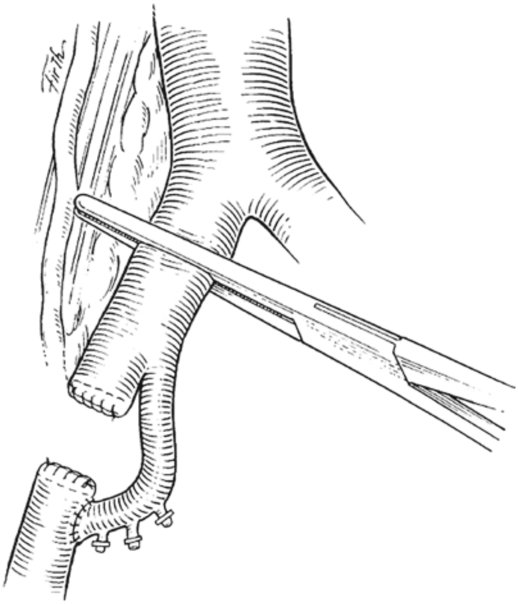

Fig. 11.10 Transposition of the internal iliac artery to the external iliac artery to restore extremity flow after an injury to the proximal external iliac artery. (Reproduced with permission from Lee and Bongard, Surgical Clinics of North America 2002;82:21–48)

external iliac artery injury is an internal iliac to external iliac transposition procedure (Fig. 11.10). Debride and completely divide the injured external iliac artery after ligating the proximal end, then divide the internal iliac artery and transpose the proximal end to the distal end or side of the injured external iliac to restore flow to the leg. Shunts can and should be utilized if the patient is in extremis. In the case of massive contamination and an unstable patient, the ends of the iliac can be ligated, living tissue placed over the stumps (omentum, etc.), and femoral to femoral bypass performed once the patient is stable. If the iliac veins suffer simple injuries, they can be repaired primarily with 3-0 and 4-0 prolene sutures. For longitudinal injuries to the vein, using the index finger and the middle finger for venous control and sewing in a running style is an efficient method for repair. If the iliac veins need to be ligated, elevation and wrapping of the affected ipsilateral extremity should be performed and you should consider fasciotomy. If you have a combined arterial and vein injury, fasciotomy of the affected calf should routinely be performed.

One of the most vexing problems is the penetrating pelvic injury to the sacral plexus. Most of the time, obtaining control in this region is difficult and packing is performed. In the majority of these injuries I have encountered there is concomitant sigmoid or rectal injury, and I have found dividing the rectum below the injury and mobilizing the rectal stump in the retro-rectal plane allows for improved visualization and packing of this area. If there are large bleeding veins visualized in that area, figure of eight sutures or U-stitch control with pledgeted 4-0 prolene sutures is an effective measure of control. Even though the veins in the area are the problem, obtaining control of the internal iliac arteries can help slow bleeding in the area and in dire circumstances the arteries can be ligated. Complete pelvic vascular exclusion can be obtained by clamping both common iliac arteries and veins. Combined with pelvic packing, this approach may be effective to finally obtain control of this difficult problem. Another option that has been used successfully in several cases of massive pelvic hemorrhage has been the application of a hemostatic dressing, such as QuikClot®. This can be left in place and removed at a subsequent exploration in 24–48 h.

Damage Control in Abdominal Vascular Trauma

All major vascular injuries to the abdomen should have a planned second look procedure. Temporary closure can be performed via numerous techniques. As stated above, certain arteries can be ligated with impunity (the celiac trunk and its branches and the internal iliac artery) while others must be repaired or bypassed (SMA, common and external iliac artery). Intra-luminal shunts can be placed with a plan for a second look procedure and repair. The warning should always be if the patient is stable for repair ***then do it*** now. Placing a shunt is not without risks, especially intra-abdominal shunts. These can lead to exsaguination if dislodged during movement and may have severe sequelae if they occlude prior to definitive repair.

The Massive Pelvic Disruption

Many of you may be familiar with the difficulties encountered when managing a patient with a severe pelvic fracture and associated bleeding. In general, the civilian algorithm for this is to not operate and to use adjuncts such as external fixation, pelvic sheeting, and angiographic embolization to control hemorrhage. Residents are often warned about the dire consequences of opening a zone III hematoma from blunt trauma. Although you may not be expecting to see blunt pelvic fractures in a combat setting, these are not infrequent injuries seen with explosive blasts or vehicular crashes. The difference is the mechanism is usually more severe, they typically also have penetrating fragment injuries, and you are in an austere environment. In the combat setting you will likely not have the option of angiographic embolization to control the hemorrhage and a pelvic surgeon ready to throw on an external fixator. You must control the hemorrhage in the OR the old fashioned way. There are several key points to remember if you are in this scenario: (1) if the patient is unstable, the abdomen should already be open to rule out intraperitoneal hemorrhage, (2) throwing lap sponges on top of a large pelvic hematoma does not provide tamponade – you must violate your instincts and open it, (3) widely open the pelvic hematoma and THEN pack the pelvis, (4) if the patient remains unstable, ligate the internal iliac artery on the more injured side, and (5) if they are still unstable, ligate the other one.

Tips and Tricks

We all know the surgeon who claims to have saved a patient by placing a Foley catheter somewhere other than the bladder. The anecdotal “trick” can work once in a while, but nothing beats sound standard operative exposure and control. The exception is if one is facile with intra-luminal occlusion balloons and placing long sheaths in the aorta and iliacs to control the major vessels remotely. However, what may be true at a Level I trauma center at home is likely not the same scenario you will face in a combat hospital. First, the rooms are often crowded with two simultaneous cases going; trying to get a C-arm in place may be impossible. Second, unless there is an experienced endovascular surgeon setting up the equipment (wires, sheaths and catheters), obtaining the necessary equipment in a timely fashion may lead to unacceptable time delays. Often simple procedures such as diagnostic arteriograms can be performed during the routine slower times, but when there is massive chaos and an unstable patient this can be a difficult task to accomplish.

Final Thoughts

Remembering what your surgical mentors have told you before a board examination is useful, and one of the most important lessons is – ***do not invent operations!*** Trust in your training and you will get through the situation. Also, you are going to be placed in situations in which you are uncomfortable. Do not compound the problem by trying to do a technique with which you are uncomfortable. For example, if you are comfortable with a transperitoneal exposure of the iliac artery do not try a retroperitoneal approach to the expose the artery. During the time of your deployment or frontline experience you will gain confidence and hone the skills you have been taught in residency and realize all of these scenarios can be handled properly. In the end, remember what your mom told you when you were young and suffered a cut; “Hold pressure….”

Chapter 12
To Close or Not to Close: Managing the Open Abdomen

Craig D. Shriver and Amy Vertrees

Deployment Experience:

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Chief Triage Officer/Surgeon, 5th MASH FST, Op Just Cause, Panama, 1989–1990

BLUF Box (Bottom Line Up Front)

1. Leave the abdomen open to save time needed for closure, allow for second looks, and prevent abdominal compartment syndrome.
2. Return to the operating room based on patient physiology and not an arbitrary time.
3. Temporary closures should control heat loss, fluid shifts, and contain and PROTECT viscera.
4. Close the abdomen if you can. When in doubt, leave the abdomen open.
5. Beware of abdominal compartment syndrome: drop in urine output, abdominal distention, and increased ventilator requirements.
6. Reverse factors causing open abdomen: control contamination and sepsis, judicious use of fluids, improve ventilator status.
7. Avoid further loss of abdominal domain – use adjuncts to prevent fascial retraction.
8. The primary factor in success or failure of obtaining fascial closure is YOU – be aggressive and aim for closure within 5–7 days of injury.
9. Avoid planned ventral hernia and the associated high rate of fistulae.

As long as the abdomen is open, you control it. Once closed it controls you.

Unknown

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No matter what your previous experience or surgical practice has been, you will extensively use and be exposed to damage control abdominal surgery and the open abdomen in combat or disaster surgery. If you are looking for level I evidence based medicine on how to approach and manage these patients, you are out of luck. You may have seen multiple different techniques of temporary abdominal closure and approaches to achieving definitive abdominal closure, many of which claim to be the optimal approach. Like most things in surgery, there is more than one way to achieve an excellent outcome for your patient. The critical factors are to develop a thorough understanding of the basic principles and pitfalls of open abdominal management, as well as your local capabilities and limitations. This chapter outlines a general approach to the open abdomen based on years of experience with combat casualties in the Iraq and Afghanistan conflicts. The basic principles outlined here are universal, but the details and techniques can and should be adapted or adjusted based on your individual situation and the realities on the ground.

Why Leave the Abdomen Open?

The abdomen is left open in specific circumstances: as part of a damage control strategy, planned second look operations, and prevention of abdominal compartment syndrome. This is no different than what is done for civilian trauma. However, in the combat setting the open abdomen will be used much more liberally for several additional reasons. In general, combat injuries will be more severe and more often multi-system. Multiple fragment wounds or blast injuries have a higher potential for missed injuries or progression of injury that can be identified at a second look operation. Limited time, limited supplies, and multiple casualties waiting for an operation will often mandate rapid temporary closure even in situations where you might otherwise perform a definitive closure. And don't forget to consider the evacuation process – you cannot monitor your patients for missed injuries or the development of catastrophic abdominal complications or compartment syndrome if they are on a helicopter or airplane.

Damage control surgery is required for the seriously injured patient, when it is critical to get in and get out and avoid the lethal triad of metabolic acidosis, coagulopathy, hypothermia. Rapid initial surgeries have specific goals: control hemorrhage by ligating, repairing or shunting injured vessels or packing solid organ or pelvic injuries. Contamination must be controlled by identifying injuries to bowel and repairing, diverting, or stapling ends without any attempt at anastomosis. By accomplishing only what is absolutely necessary, the patient can be taken to the ICU to continue resuscitation and prepare the patient for more definitive operations when they are more stable. The abdomen is closed temporarily with either skin closure only with whip stitch or penetrating towel clamps, or more commonly with temporary dressings detailed below.

Packing is an essential component of damage control if bleeding from solid organ or venous injury is present. The abdomen is packed, temporary closure is achieved, and the patient is stabilized prior to further treatment of the injuries.

Packing must provide enough pressure to tamponade bleeding, but care must be taken to not compress the inferior vena cava and decrease venous return to the heart. Hypovolemia is often present in this scenario, exacerbating the problem. If patients cannot be stabilized after packing, reassessment of the packing and temporary closure should be undertaken. Although time is a critical factor in these patients, do not just assume that a panicked abdominal packing is an adequate damage control procedure. **An extra 10 or 20 min in the OR to assure that you have adequate hemorrhage and contamination control is much preferred to watching your patient bleed out from their abdominal wound in the ICU**. Abdominal compartment syndrome is still possible with vacuum-closures and other temporary closures, and may prompt an early return to the operating room or a bedside laparotomy in the ICU.

The abdomen should always be left open if a second look is planned. This is especially useful if the second look will be done by another surgeon at a higher level of care. Clearly dead bowel should be resected, however it is not always obvious if bowel cannot be saved. If there is a question of bowel viability at the initial surgery, an extensive resection of potentially viable bowel should be avoided and a second look should be planned. Bowel viability may improve with continued resuscitation, and prevention of extensive resection is necessary to avoid short gut syndrome. Anastomoses in a patient with potential for deterioration are risky and so are often better served by delay until a subsequent return to the OR. An ostomy could be avoided if the patient remains stable after the initial operation, and an ostomy can be formed at the second look if the situation for an anastomosis is not ideal. A failed anastomosis that is not immediately recognized can lead to overwhelming sepsis requiring significant fluid resuscitation and virtually guarantee an open abdomen that is difficult to close.

It is critical to identify abdominal compartment syndrome (ACS) and predict patients who may develop this syndrome. Unfortunately we have no absolute measures for predicting which casualties will go on to develop ACS. Patients that are already acidotic, hypothermic and coagulopathic are the highest risk for ACS, and should be left open. Other high risk factors are patients receiving massive transfusion or large volume resuscitation, large thermal injuries, high grade liver injuries, and mesenteric vascular injuries. The abdominal domain is limited, and excessive visceral or retroperitoneal edema, blood, gas, ascites or stool can cause systemic life-threatening problems. Abdominal compartment syndrome can occur in patients without intra-abdominal injuries (secondary ACS) in cases of substantial bowel or retroperitoneal edema from massive fluid resuscitations or systemic inflammatory responses with capillary leak causing extensive interstitial edema. Clinical signs of ACS include a tight and distended abdomen, hypotension, low urine output, and rising ventilatory peak pressures. This clinical picture should prompt immediate opening or re-opening of the abdominal cavity. One exception to this rule is the patient who has a purely secondary ACS, which is usually due to massive volume resuscitation and the buildup of tense abdominal ascites. This is commonly seen in injured patients with significant burns. A quick bedside ultrasound or diagnostic tap can identify the presence of massive ascites, and these patients may be better managed by large volume paracentesis or placement of a percutaneous drain.

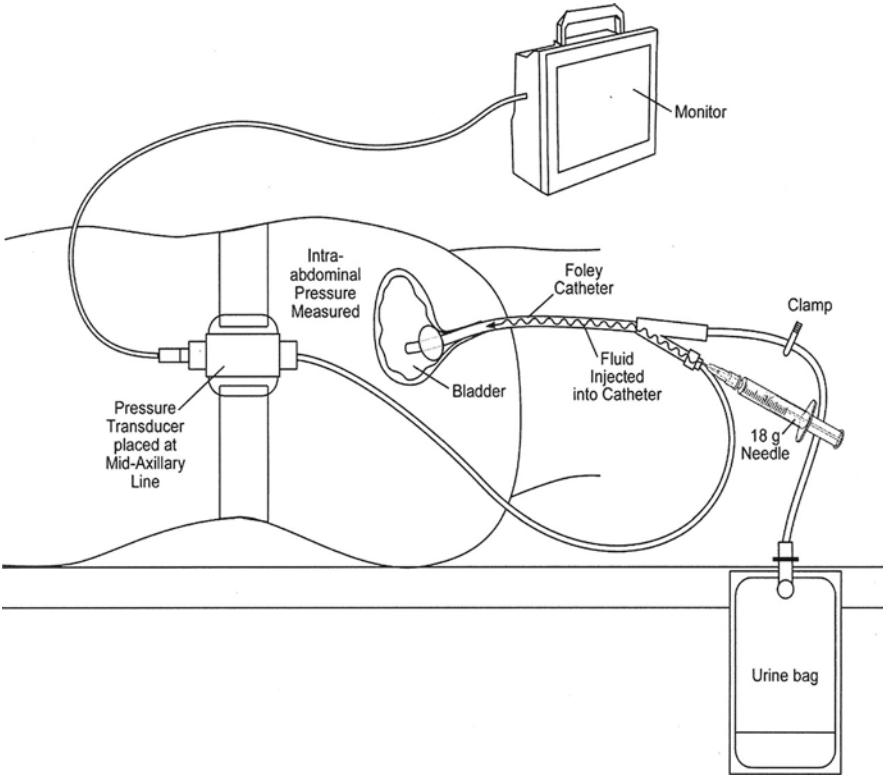

Fig. 12.1 Demonstration of bladder pressure measurement. Reproduced with permission, Mullens et al., JACC 51(3), 2008

Measurements of intra-abdominal pressure are useful for identifying impending or active ACS, and are usually achieved by indirect methods. Bladder pressure is most commonly used (Fig. 12.1): the bladder is decompressed with a Foley catheter, 50–200 cc of sterile saline is infused into the catheter, and the catheter is then clamped distal to the area of pressure measurement. A pressure transducer with a needle (like that used for arterial pressure measurements) is used to puncture the hub of the Foley as shown in Fig. 12.1. The transducer should be zeroed at the symphysis pubis with the patient in a supine position and then allow the waveform time to equilibrate. Although bladder pressure is most commonly used, you can measure intra-abdominal pressure via any hollow structure in the abdominal cavity. Alternative methods of indirect measurements include intra-gastric (NG tube) or inferior vena cava pressure through the femoral vein. If pressure transducing equipment is not available, see Appendix A for a low-tech bedside method of estimating bladder pressure.

Although every patient may respond differently, organ dysfunction increases with increasing intraabdominal pressure (IAP), and a value of >25 mmHg has been suggested as a target for decompression. Reopening and reexploration is recommended for anyone with a pressure above 35 mmHg. One pitfall you have to take into consideration is that these pressure cutoffs generally apply to normotensive patients.

Abdominal compartment syndrome can occur with bladder pressures of less than 20 in patients with hypotension! Think of the abdominal cavity like the cranial vault – the perfusion pressure will be a function of the mean arterial pressure (MAP) minus the abdominal compartment pressure. Therefore, if the MAP is already low, then even an abdominal pressure of 15 can result in a perfusion pressure that is inadequate. Remember that abdominal compartment syndrome is a **clinical diagnosis** – no single test is absolutely necessary for the diagnosis and treatment of ACS. A patient with a tight abdomen and who is difficult to ventilate should have consideration given to opening the abdomen. When in doubt – open a closed abdomen or leave the abdomen open.

How to Temporarily Close the Open Abdomen

Intra-abdominal contents must be protected from desiccation and from insensible losses. Temporary closures have been used to achieve this goal, and many different types of closure have been described. The most common method of temporary closure involves using any type of plastic occlusive barrier such as large sterile irrigation bags or Steri-Drape® (3M®, St. Paul, MN) plastic sheeting with small slits cut in the plastic to allow egress of fluid. A sterile X-ray cassette cover will also work very well – use a scalpel to make multiple small slits in the plastic to allow fluid to flow into the vacuum component. This sheeting is then tucked under the fascia down to the pericolic gutters (Fig. 12.2), ensuring that all exposed bowel is covered and protected from direct contact with any sponge material. Laparotomy sponges or operative towels are then placed over the plastic barrier, with drains

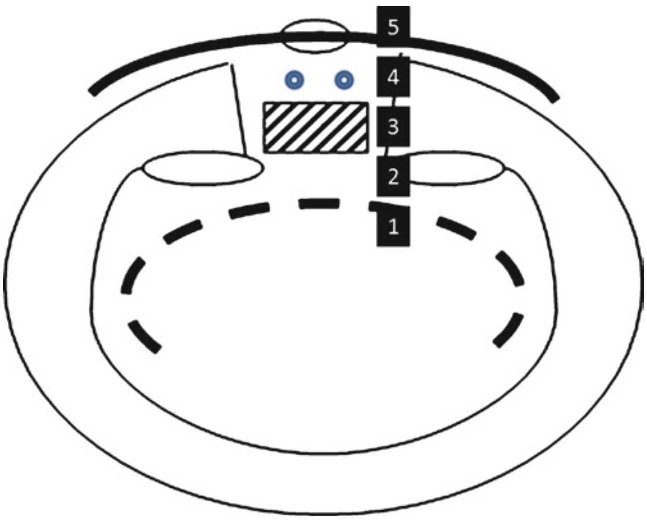

Fig. 12.2 Plastic draping tucked underneath the fascia to the pericolic gutters (1). Mesh to fascial edges for serial closure and prevention of retraction (2). Towels, lap sponges or KCI® V.A.C. sponges (3). JP, NGT, or chest tube drains (4). Ioban® or KCI® adherent dressing (5)

within or on top of the sponges. An occlusive dressing like Ioban® (3M®, St. Paul, MN) is then used to seal the wound. Fluid egress is achieved with large tubes (often nasogastric tubes with the air vent portion of the sump drain tied into a knot, chest tubes or 2 JP drains) placed on top of the towels or gauze and underneath the occlusive dressing with attachment to continuous wall suction. It is important to create a "mesentery" with the Ioban® around the tube used to prevent leaks and pressure on the skin (Fig. 12.3a, b).

Fig. 12.3 Demonstration of temporary abdominal closures. (**a**) Irrigation bag, gauze and JP drains shown after Ioban® removed; (**b**) Operative blue towel over a chest tube and covered with Ioban dressing. A mesentery is formed over the Ioban® to prevent leaks; (**c**) Abdominal wound vac closure with skin edges sutured partially closed over vac sponge to maintain tension and prevent retraction

An excellent option that is now commercially available is the temporary abdominal closure kits or "Abdominal Wound-Vac" (V.A.C.® dressing, Kinetic Concepts, Inc.). This all-in-one sterile pre-packaged kit provides a polyurethane foam dressing sandwiched in between perforated plastic sheeting, large oval vac sponges, adhesive drapes, and an adhesive pad with suction tubing. The sponges can be secured to the skin edges with several staples, or alternatively the skin can be sutured closed (fully or partially) over the top of the sponges. The suction tubing is then connected to a self-contained vacuum device which can provide varying levels of continuous or intermittent suction and fluid collection. It has been our experience that the use of negative pressure systems for temporary abdominal closure greatly improves the ease of postoperative nursing and wound care, and also improves the rates of early primary fascial closure.

The method of closure used is not as important as following the basic principles of visceral coverage and protection, fluid and contamination control, maintenance of abdominal domain, prevention of fascial retraction, and prevention of compartment syndrome. You should develop an agreed upon method of temporary abdominal closure with your group of colleagues, and have all materials pre-packaged and readily available to minimize operative delays. If you develop a well considered standard algorithm for temporary abdominal closure, open abdomen management, and abdominal closure then you will see improved results, decreased complications, and improved fascial closure rates.

Serial Abdominal Closure

Successful final closure involves planning ahead. Reversal of causative factors, prevention of fascial retraction, and avoidance of the visceral block adhering to the abdominal wall are the most important considerations. Reversal of causative factors including judicious use of fluids (strategies and end points of resuscitation are covered in another chapter), controlling contamination, preventing and treating sepsis, and improving ventilator status to prevent visceral edema from high positive end expiratory pressure (PEEP). Figure 12.4 demonstrates an algorithm outlining the approach and timeline for closure of the open abdomen. Ideally, primary closure should be achieved within 7–10 days, and should be accomplished in the majority of open abdomens (70–90%). If you are not able to achieve primary closure within this time period, prevention of fascial retraction and serial closure should be initiated.

Prevention of fascial retraction involves some method of adherence of the fascia to hold on to the edges as the inevitable retraction occurs. We have frequently used mesh as a serial closure device (Figs. 12.5a–d). Goretex Dualmesh® is sewn to the fascial edges to contain the abdominal contents and prevent fascial retraction. A wound vacuum dressing is placed over the mesh. The wound vacuum sponges are changed every 2–4 days, and the mesh is lifted to determine if abdominal domain can be reclaimed. This is often once or twice a week, with a couple of centimeters trimmed

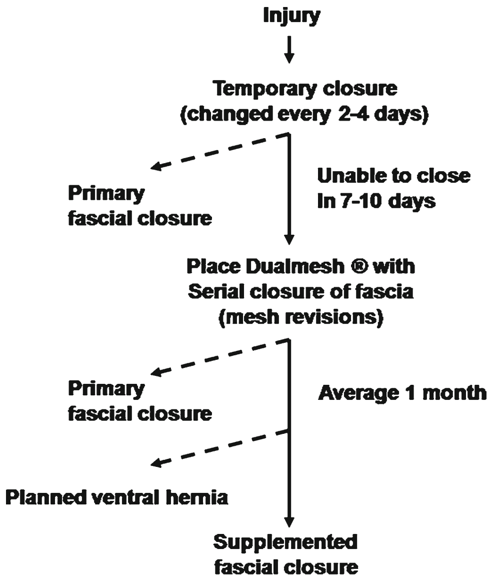

Fig. 12.4 Timeline for abdominal closure

off the middle of the mesh each time and reapproximated with Prolene® or PDS® suture. Serial closure techniques that provide traction to the fascial edges may result in macerated fascial edges that need to be debrided to allow proper healing and avoid hernia recurrence. Our previous closures have required supplemental material to finally close the abdomen once serial closure is complete and the Dualmesh® prosthesis has been removed; of note is the fact that the Dualmesh® is ALWAYS a temporary "bridge" and never should be left as the definitive closure material; it is contaminated (by definition) and must be explanted once it completes its "job" as a bridge temporary abdominal containment material. Polypropylene mesh has been used as the final replacement mesh, with very low infection and fistula formation rates in our experience. Biologic mesh seems ideal in a contaminated field, but has a high rate of failure and will most certainly lead to a planned ventral hernia, as the biologic material bridging a fascial gap does not become fascia; it becomes scar and that means a ventral hernia. We have recently modified our technique with placement of a 10–10 plastic drape (Steri-Drape® from 3M®, St. Paul, MN) beneath the Dualmesh®, which prevents adherence of the abdominal wall to the visceral block. This allows more movement of the abdominal wall and increases the possibility of primary closure. It also allows access to the underside of the fascia for underlay mesh if desired.

Inability to place mesh or failures of serial closure has required planned ventral hernia (PVH). In this technique, if there is no granulation tissue, vicryl mesh is sewn to the fascial edges. If there is adequate skin and subcutaneous tissue that can be mobilized to cover the wound, then primary skin closure can be performed over multiple subcutaneous closed-suction drains. If there is inadequate native abdominal

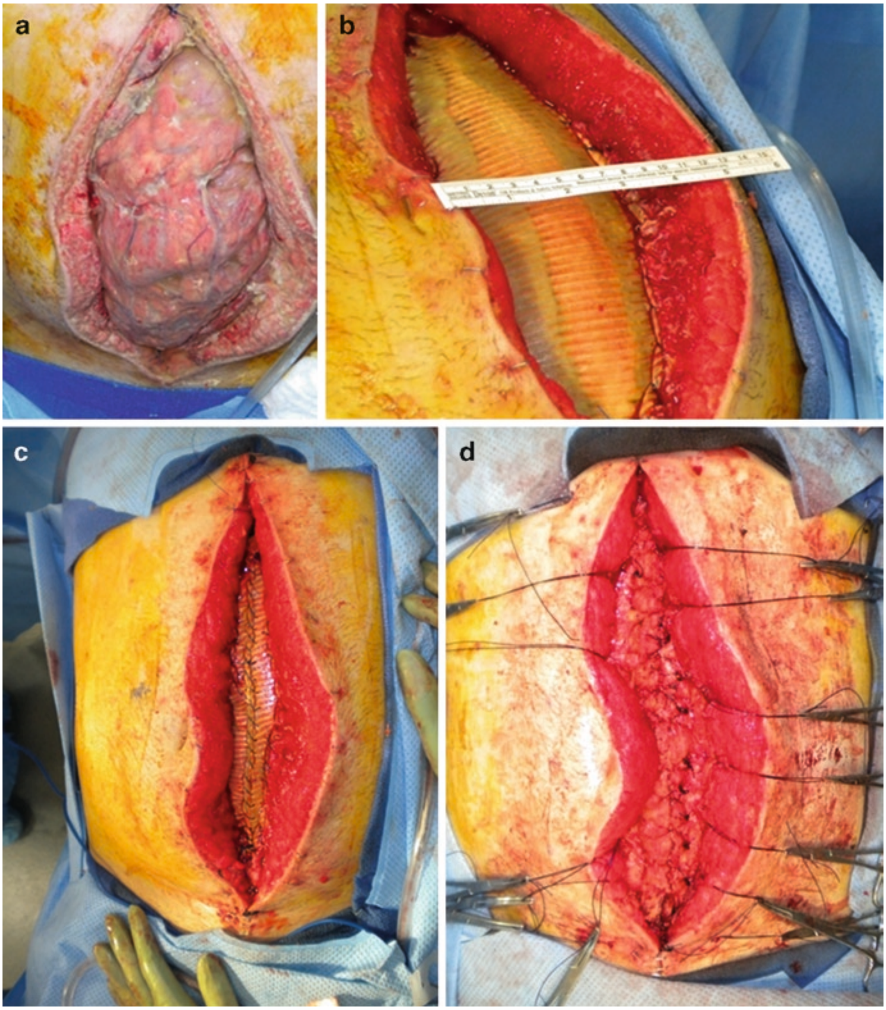

Fig. 12.5 (**a**) Open abdomen. (**b**) Dualmesh® sewn to fascial edges. (**c**) Mesh revision of Dualmesh®. (**d**) Dualmesh® removed and fascia primarily closed. A FlexHD® underlay was placed in this patient

skin, then coverage must be provided by other means. Once an adequate granulation bed has formed over the Vicryl mesh, a split thickness skin graft is placed over the granulation tissue and viscera. This results in a large hernia that can be repaired in 6–12 months. This method of closure is associated with a high rate of enterocutaneous fistulas. We seek to avoid PVH at all costs, and in our published experience and long-term follow-up this method should be and is unnecessary in wounded warriors. The techniques described in this article and our publications that avoid PVH are the standard in 2009 and beyond.

Complex Abdominal Wall Reconstruction: Component Separation

One basic principle is that you will usually be better off from a closure and infection standpoint if you can achieve fascial reapproximation with native tissue and avoid the use of prosthetic mesh. However, if there is a large fascial gap that cannot come together without undue tension, then the traditional answer has been placement of a mesh bridge. An alternative and increasingly popular approach being used by both civilian and military trauma surgeons is the technique of component separation, or "separation of parts" closure of the abdominal wall. This is a technique that should be understood by all combat surgeons, and is particularly useful in situations where you may have limited availability of mesh products (and almost never have access to biologic mesh).

Fascia of the abdominal wall can be manipulated with components separation of the fascial layers (Figs. 12.6 and 12.7). Complete components separation in some surgeon's hands can theoretically bridge gaps up to 20 cm, but is associated with significant reherniation rates. A more reasonable expectation for this technique is to bridge gaps of 5–15 cm. In planning for this type of repair, one requirement is that

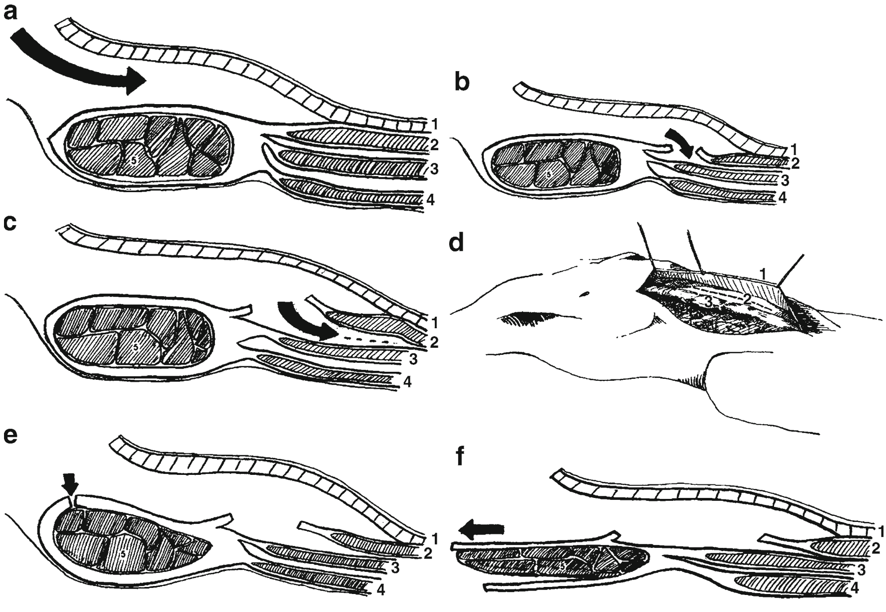

Fig. 12.6 Components separation technique. (**a**) Subcutaneous flaps are raised over the rectus and external oblique; (**b**) Longitudinal division of the external oblique aponeurosis at its insertion into the anterior rectus sheath; (**c**) and (**d**) The external oblique is freed from the internal oblique as far laterally as possible; (**e**) and (**f**) If additional length is needed, the medial rectus sheath is opened longitudinally and the rectus muscle is mobilized off of the posterior sheath. (Reprinted with permission from J Am Coll Surg 2003;196:32–37)

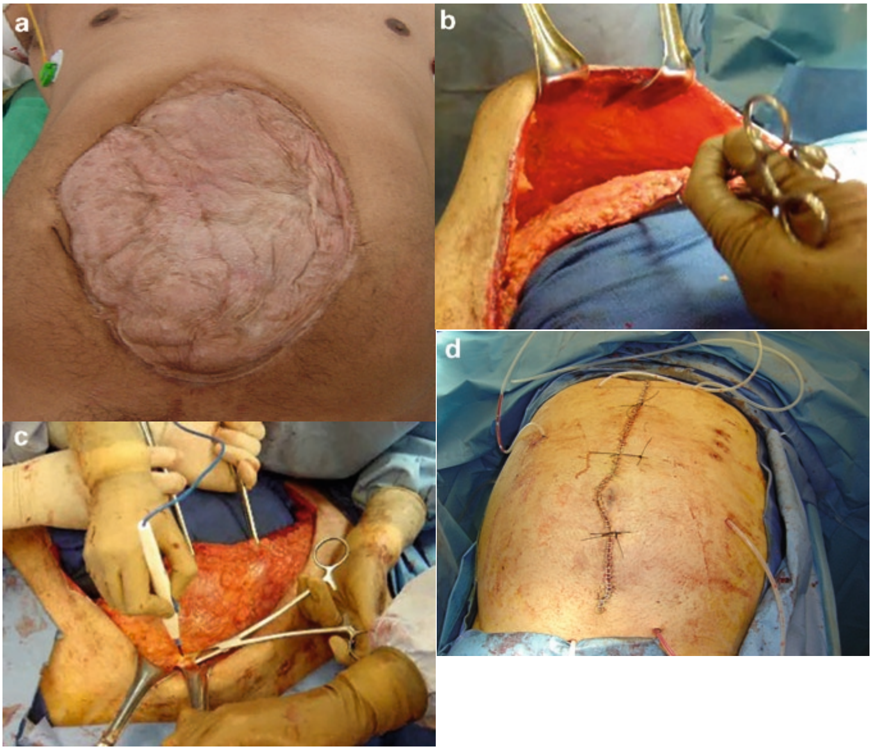

Fig. 12.7 Component separation procedure following damage control laparotomy. (**a**) Large ventral hernia with skin graft on bowel; (**b**) skin flaps are raised circumferentially over anterior rectus sheath and external oblique aponeurosis; (**c**) division of the external oblique aponeurosis as it inserts into the lateral rectus sheath; (**d**) excess skin is resected and closed primarily over drains

you must have the majority of the rectus muscle and sheath intact, which can be assessed with a preoperative CT scan or intraoperatively. Identify the anterior rectus sheath and raise lateral skin flaps circumferentially until you can identify the lateral rectus border and the insertion of the external oblique aponeurosis. The external oblique aponeurosis is then divided longitudinally from the costal margin to the inguinal ligament. You should see a flimsy layer of fat and wispy connective tissue below the aponeurosis – if you see muscle then you are too far medial or lateral. Grasp and elevate the cut edge of the aponeurosis laterally while retracting the rectus muscle medially. This exposes the connective tissue layer deep to the aponeurosis which can be divided all the way out to the mid-axillary line. If this does not provide enough mobilization for fascial closure, then the rectus muscle can be rolled anteriorly allowing longitudinal division of the posterior rectus sheath. This will provide an additional 2–3 cm on each side. The fascial edges can now be approximated primarily with running or interrupted suture – we prefer interrupted figure of 8 Prolene. The “open book” is a variation of components separation where the lateral aspect of the rectus sheath is incised on both sides of the abdominal wall, and folded medially to form a new midline. The medialized edges are then sewn together. There are now multiple series reporting excellent functional results with low complication rates and low recurrent herniation using the modern component separation approach.

Supplemental closures materials are available with individualized benefits and complications. Plastic mesh (polypropylene, Goretex®) is associated with increased adhesions, fistulas, and infections. They are best used in a noncontaminated field with interposed tissue such as peritoneum or omentum to decrease wound complications. Biologic mesh (Alloderm®, Surgisis®, FlexHD®) became rapidly popular for their advertised strength and ability to withstand infection or contamination. However, the accumulation of experience has revealed that these materials have a high failure rate (>50%) when used as a fascial bridge or when subjected to exposure and desiccation in open wounds or with vacuum closure. However, they may be the only good option in a contaminated field to provide temporary closure and protection. There is also a growing anecdotal experience of improved outcomes with the component separation technique when the fascial closure is reinforced with a biologic mesh underlay or overlay. We have used this technique with excellent results, and recommend the material be placed in the underlay position with at least 4–6 cm of overlap and that moderate tension be achieved to prevent laxity.

Specific Pitfalls and How to Avoid them

Specific pitfalls in open abdomen management include not leaving an abdomen open that should be, not recognizing the need to reexplore or adjust dressings, enterocutaneous fistula formation, allowing retraction of fascia or adherence of the visceral block to the underlying abdominal wall, and leaving packs in the abdomen. All of these can be avoided or minimized with a standard and careful team approach to these patients.

Abdominal compartment syndrome (ACS) must be either prevented or treated promptly when recognized. Temporary closures will not prevent the need to reexplore if a surgical treatment is necessary, and ACS still occurs with temporary packing. One of the most common causes of ACS in the patient with an open abdomen from trauma is recurrent intra-abdominal hemorrhage. This should be rapidly recognized by a dropping hematocrit, hemodynamic changes, and bloody output from the abdominal wound. This should prompt immediate re-exploration which should be performed in the operating room. **Do not attempt an exploration for bleeding at the bedside!** If it is suspected that the temporary closure is simply too tight, then the vacuum suction can be released, any skin closure should be opened, or the dressing can be removed and replaced under no tension. Alternatively, if the fascia was not fully opened at the initial operation, then extension of the incision may be needed. Chemical paralysis of the patient, particularly if there is any obvious agitation or increased muscle tone, can often improve the situation or temporize until definitive intervention can be accomplished.

Enterocutaneous fistula is a miserable complication in the open abdomen patient, and prevention is the best strategy. Usually any type of primary repair of these fistulae is doomed to failure, and your goal should be to achieve adequate control and drainage. To prevent this complication optimize nutrition, close the abdomen as soon as possible, and protect the underlying bowel at all times. If a fistula develops, try to convert it to an enterocutaneous fistula by achieving adequate drainage well off of the midline. If you are unable to do this, then you are left with the very difficult problem of an enteroatmospheric fistula draining directly into your open abdominal wound. This is an entirely different and more difficult entity, since it will continuously soil the abdominal cavity, wound, and fascial edges. The lack of surrounding skin precludes the placement of an ostomy appliance or other device to easily control the effluent. Your goal now should be to mature the fistula and surrounding tissue to a point where an ostomy appliance can be applied while also protecting the remaining exposed bowel. If the skin can be closed above and below the fistula, then it can be converted to a "floating ostomy" directly in the midline wound. If not, then placement of a wound vac sponge with a defect cut out directly over the fistula will allow drainage and placement of an ostomy appliance while also protecting and maturing the surrounding tissue. Alternatively, the fistula(ae) can be intubated with a drainage tube (Malecot catheters) which is brought through the wound vac sponge (see Fig. 12.8).

Loss of the abdominal domain is associated with retraction of fascia, so use supplemental material if necessary to prevent retraction. If you maintain some degree of tension on the skin by partial or complete closure over the vac sponges, you will prevent some degree of fascial retraction. The visceral block will adhere to the underlying abdominal wall and decrease your chances of primary closure, so ensure that plastic sheeting goes all the way down to the pericolic gutter. This will also provide an access to the fascia for supplemental underlay of mesh. Finally, always remember to double check the entire abdominal cavity for retained packs and get an X-ray before final closure; the sponge count is always unreliable in damage control surgery.

Final Points

Damage control surgery is an excellent tool in seriously injured patients. Open abdomen management is required for many of these patients. If there is a doubt about visceral edema, contamination, or need for second looks, then plan for the worst case scenario and leave the abdomen open. This is especially true if there will be a discontinuity of care providers in the evacuation chain. Eventually, the abdomen should be closed within several weeks of the primary injury. Keep the end goal in mind and set yourself up for a successful closure with protection of viscera, prevent fascial retraction and adherence of viscera to the abdominal wall, and control factors contributing to the loss of abdominal domain. There are many techniques available to assist with abdominal closure. Serial abdominal closure allows reclaiming the abdominal domain over time. Mesh is available

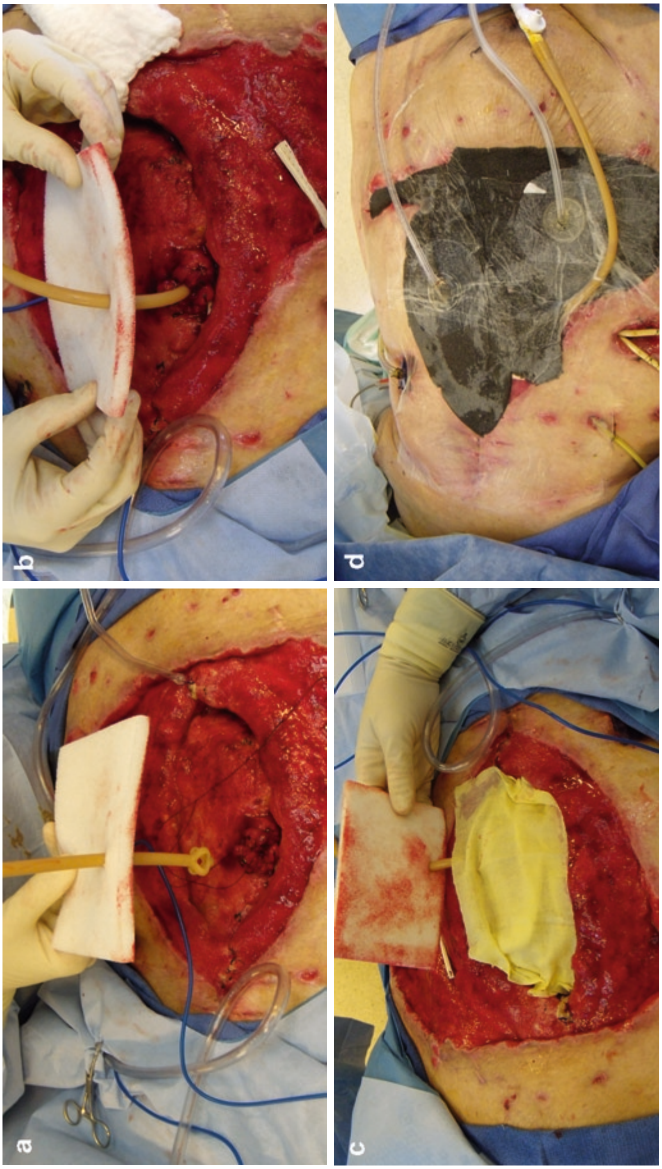

Fig. 12.8 Wound vac and Malecot drain management of an open abdomen with enterocutaneous fistula. (**a**) 20 French Malecot drain is brought through a hole in a *white wound vac sponge*; (**b**) The fistula is intubated with the drain and sponge is cut to fit the defect; (**c**) A layer of non-adhesive dressing (Xeroform shown) is applied between the vac sponge and exposed viscera; (**d**) Completed dressing with standard *black vac sponges*

for final closure, although timing and choice of mesh materials as described in this and other articles from the authors, will impact success rates. Components separation is another excellent technique available to assist with abdominal closure. Above all else: when in doubt, leave the abdomen open!

Chapter 13
Choice of Thoracic Incision

Jeffrey A. Bailey

Deployment Experience:

Jeffrey A. Bailey	Chief of Trauma ("Trauma Czar"), 332nd Expeditionary Medical Group, Air Force Theater Hospital, Balad Air Base, Iraq, 2006–2008

BLUF Box (Bottom Line Up Front)

1. We are not here to cure cancer or treat angina; trauma is the game.
2. Positioning is the key to keeping your options open.
3. If you find yourself putting the patient in anything other than supine position for an exploratory trauma operation, think about it again.
4. Keep your options open – you may be wrong about where to go first a third or more of the time.
5. Get the exposure *you need* to get to the ABCs.
6. Do not let anatomical barriers interfere with your ability to get to the ABCs (the sternum is just a bone, so is the clavicle).
7. Chose your incision and know when and how to modify, extend, or abandon it.
8. Don't worry about the injuries you've found – worry about the possible injuries you haven't found yet and how you're going to get there.
9. The first maneuver if you find yourself struggling should be to enlarge the incision.

Pray before surgery, but remember God will not alter a faulty incision.

Arthur Keeney, 1920

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Why This Chapter Matters to You

No one is going to thank you for leaving fewer or smaller wounds on a corpse – leave your handbook of minimally invasive and aesthetic technique at home – this is not boutique surgery. Also, don't get confused – we are not here to cure cancer or treat congenital or age related cardiovascular disease. That stuff you will find in the handbook of *elective* cardiothoracic surgery. That all applies where the specialized and circulatory-supported are the only surgeons regularly entering the chest. We are going to a place where the general surgeon is likely the only hope a patient has for surviving after a thoracic wound. That hope will be vested in *you*. Fortunately it is also a place where the experienced general surgeon is likely to know a lot about the priorities and pitfalls of thoracic surgery for trauma. But the rub is that even among seasoned trauma and combat general surgeons, there is limited (though highly intense) *individual* experience. It's a very difficult area in which to get a wealth of experience because only a small minority of thoracic injuries, even penetrating or combat related, require a major operation. In those that do require an operation the stakes are extremely high. Mortality and morbidity will stand next to you in the OR and stalk your patient long after you have placed the last staple in the incision (or incisions) you chose. Let me be frank – there may be a few personal case series experts in combat thoracic surgery, but it's highly unlikely that one will show up in your OR. Fortunately for us mere mortals, there is a collective experience on which to draw. So this chapter is written by and for the "grunt" of combat thoracic surgery – the trauma and general surgeon, with the hope that together we may tip the scale in a favorable direction for our patients and their families.

Rules of Engagement

This chapter is not about when to operate. It is not about how to perform an operation. It is about how to begin and adapt an operation based on the knowledge and skills *you bring* to the situation you face. Utility for exposure and control of the thoracic vessels and organs *in your hands* is the single most important factor in choosing an incision and for keeping your options open. With that being said, let's keep a few things in mind. There is no mandatory imaging required prior to making an incision in the chest. Though imaging may be helpful in terms of understanding trajectories or injured structures, it does nothing for fixing airway, breathing, or circulation. So be ready to make an incision based on limited information when the patient doesn't have the luxury of waiting for the exposure of an X-ray cassette. Also, be ready to modify or abandon your initial incision based on what you do – or maybe even more likely – *do not find*. The utility of the incision you choose (e.g. the extent of exposure and control potential it provides) is going to be inversely proportional to the amount of pre-operative information – especially imaging information – you have available.

"This Guy is Dying; I Need to Open His Chest…"

In addition to how to begin a thoracic operation, the decision of where to begin an operation will depend on your initial intention. If that intention is resuscitative then you may choose to begin the operation in the combat emergency department. The decision to proceed with "ED" resuscitative thoracotomy, beyond potential for salvage, should be guided by the availability of instruments, lighting, suction, and skilled assistance as well as the proximity and availability of an operating room. I recommend moving the patient quickly to the OR and beginning the resuscitative thoracotomy with the patient on the litter in the OR if an OR is immediately available and in very close proximity to the ED. The incision of choice for the resuscitative thoracotomy is a left anterior lateral thoracotomy (Fig. 13.1). This incision gives the best starting point for initial and adequate exposure of the structures in the left hemithorax and mediastinum including the pericardium, pulmonary hilum, distal aortic arch, proximal left subclavian artery, and descending aorta. If injury is not detected or controllable from the left hemithorax the incision can be extended across the sternum toward the right hemithorax as either a limited trans-sternal extension to gain better visibility for control of the left hilum (Fig. 13.2) or full extension to right anterior lateral thoracotomy or the "clam shell"

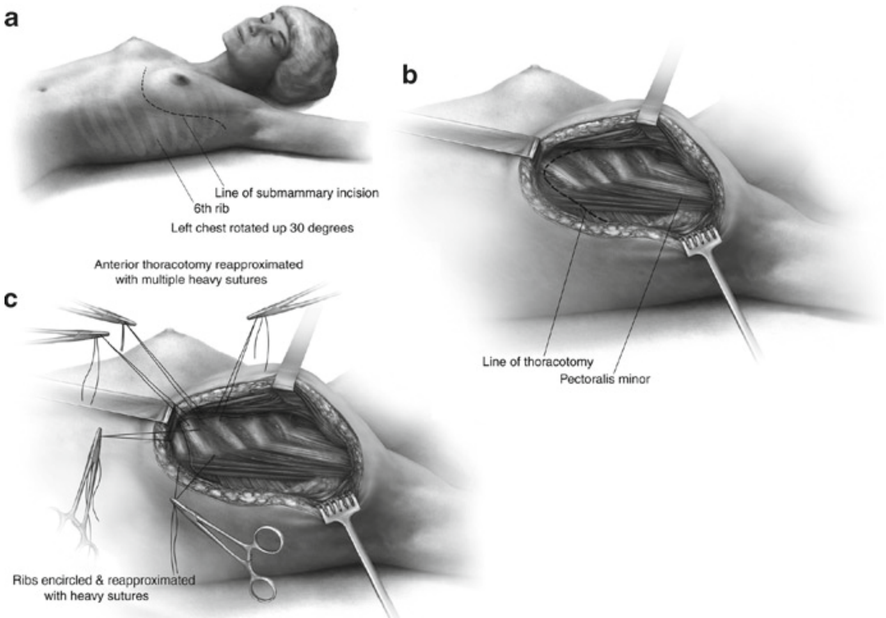

Fig. 13.1 Resuscitative anterolateral thoracotomy. (**a**) The patient should be supine, ipsilateral arm elevated, and place a roll under the back to elevate the chest anteriorly. The incision is along the inframammary crease (females) or the ribspace below the nipple (males) and extends superiorly and laterally to the table. (**b**) Deep exposure with pectoralis incised medially. (**c**) Closure with heavy sutures encircling the ribs. (Reprinted with permission from Campell, Operative Techniques in General Surgery 2008;10:778–786)

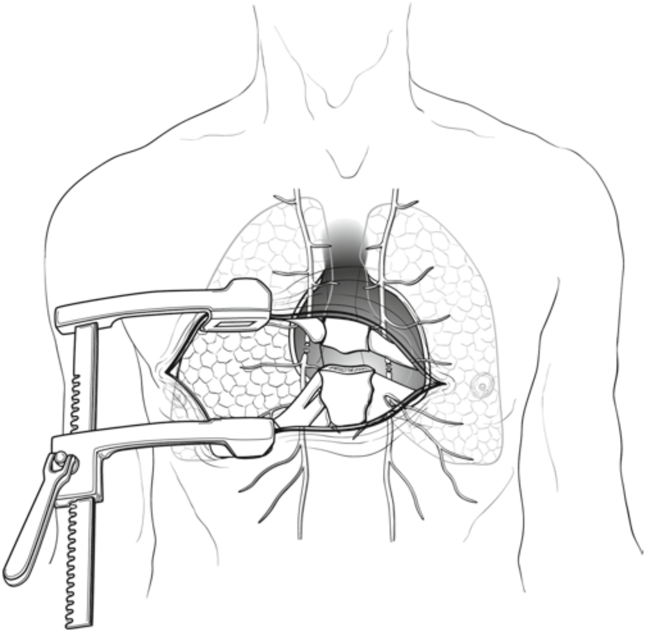

Fig. 13.2 Trans-sternal extension of an anterolateral thoracotomy. The internal thoracic arteries should be identified and clamped or ligated

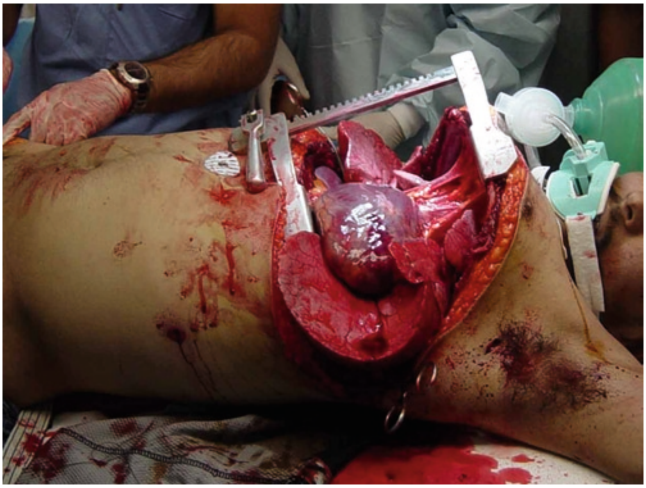

Fig. 13.3 Exposure of the thoracic and mediastinal structures by a full clamshell thoracotomy

incision (Fig. 13.3). The clam shell will provide incredible exposure of the heart and great vessels as well as the thoracic inlet. The limitation of the anterior thoracotomy is exposure of the posterior mediastinal viscera – particularly the esophagus and the posterior wall of the trachea and its major branches. Though injury to these structures is potentially life threatening, the trade off to optimal exposure is the range of options provided for exposure and control of more immediate life-threatening injury.

"We Have a Pressure We Can Work With…"

If the hemodynamic status permits transfer from the litter to the operating table owing to resuscitation or initial operative intervention, things may seem to be headed in the right direction. Perhaps you relieved a tamponade and deftly repaired an injury to the right ventricle. Perhaps the patient has been stable enough to avoid a resuscitative thoracotomy, but has concerning drainage from a chest tube and a "soft pressure." Don't get greedy. Though it is tempting to position the patient in lateral decubitus with the intent of exploring the ostensibly bleeding hemithorax via a posterior lateral thoracotomy – remember the second BLUF bullet. Simultaneous life-threatening neck, thoracic, abdominal and extremity injury is by no means uncommon with combat wounding. In the patient where the potential for multicavitary injury exists – like the initially unstable patient with limited pre-operative imaging or examination – do not close the door on going down into the abdomen, out to the proximal extremities, or up into the neck. Correct patient positioning is the pre-requisite to preserving the option of entering any of the three thoracic spaces (both hemithoraces and mediastinum), the abdominal cavity, and exposure of the proximal extremities, and the neck. That position is supine with the patient prepped from chin to knees. The most common reasons for choosing the wrong initial incision are misleading chest tube output and relying on the accuracy of physical examination to detect abdominal injury. Here is a short cautionary tale about keeping your options open.

"So what's the deal?" I ask the SOD (Surgeon of the Day).

"Shot in the right chest, posterior exit wound – just had a laparotomy at a FOB (Forward Operating Base) – he's got packs around his liver – the abdominal vac and chest tube aren't draining much – they packed the chest wound too. He looks pretty good, but the chest dressing's soaked through so I am going to scan him and then change the dressing in the OR."

Three hours later I head toward the ICU tent. The patient is in the first litter on the left.

"How much out since the OR?" asks the SOD.

"About 400 from the chest tube and about 200 from the abdominal vac," says the tech.

"Well, he dumped about 300 out of the chest tube when we turned him, but otherwise there's not been much out of that since then. But the chest dressing has soaked through," says the nurse.

I follow the tubes to the hanging bags. PRBC, FFP, and some drips…fentanyl, ativan, levophed… "When did he get started on levo?" I ask. "His pressure has been good till the last hour – we just started it – might be dilating out because he's warmed up now, but that's why I paged the SOD," says the ICU doc.

"What did you find in the OR?" I ask the SOD

"He was bleeding off the chest wall wound – but I got it stopped with some suture and more packing, that's why I didn't wake you up – thought we had it pretty well controlled, but I think we better take him back and take another look," says the SOD

> We position him in lateral decubitus, get him prepped and unpack the wound. The gauze is completely saturated. We suction the chest through the wound and see that it is full of blood. We make a posterior lateral thoracotomy and evacuate the blood which we now see is welling up into the chest from a big hole in his diaphragm.
>
> "Damn – he's bleeding from his liver – we need to get him on his back so we can get into his belly guys."
>
> I see a heart rate of 140 and a systolic blood pressure of 70 on the monitor as we pack the chest and whip stitch the skin closed on the thoracotomy. "C' mon guys – he is trying to die on us," says the anesthesiologist as we tear down the drapes and roll the patient supine.
>
> Two hours later he is back in the ICU after we debrided what was left of the right lobe of his liver, got the bleeding controlled and closed the hole in his diaphragm.

"I've Seen This Before…"

In addition to sharing this story as a means of illustrating the importance of keeping your options open, I also share it to illustrate the importance of recognizing pattern of injury. In the anecdote, the thoraco-abdominal wound pattern was recognized by the surgeons at the FOB. They chose to operate in his abdomen and they chose correctly. At our second operation we were misled by the chest tube output and abdominal examination (minimal vac drainage). Penetrating thoracic wounds may have a 40% or greater chance to be associated with abdominal injury (especially gunshot wounds). The likelihood is greatest in the thoraco-abdominal region (costal margin to nipples in front and scapular tips in back). Moreover, thoraco-abdominal wounds requiring thoracotomy and laparotomy have an extremely high mortality. If you're not convinced yet, then consider that in these life-threatening injuries you may be wrong about which cavity to enter first more than one-third of the time. The thoraco-abdominal injury pattern has a high lethality and requires positioning and exposure with the greatest versatility to gain control of injured organs and vessels in the chest and abdomen. The position of choice is the patient supine, allowing for anterior lateral thoracotomy, sternotomy, and laparotomy with options to go up to the neck or out into the proximal extremities.

"Stem to Stern Potential"

The median sternotomy is the incision with the most utility to reach the heart and great vessels. It also provides access to the pulmonary hilar structures and to a lesser extent the lungs (Fig. 13.4). It is versatile in that it can be extended into the neck and via the "trap door," out into the proximal upper extremities. The trap door will provide access to the subclavian artery and its branches including the proximal vertebral, the internal mammary and the axillary arteries (Fig. 13.5). It also allows the option for laparotomy. The disadvantage to this incision is that it provides sub-optimal access to the lungs, particularly the left lower lobe, and provides no exposure

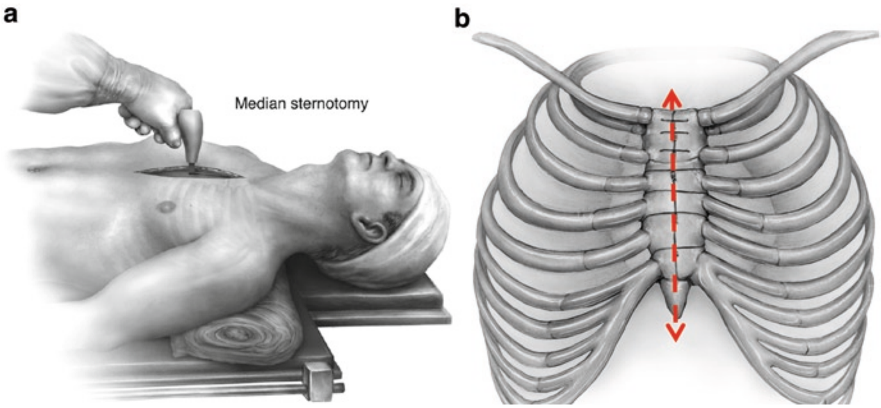

Fig. 13.4 Median sternotomy incision from 2 cm above sternal notch to 2 cm below xiphoid (**a**). The sternum is then opened with a power sternal saw (**b**) or a Lebske knife, with no lung ventilation during sternal division. (Reprinted with permission from Campell, Operative Techniques in General Surgery 2008;10:778–786)

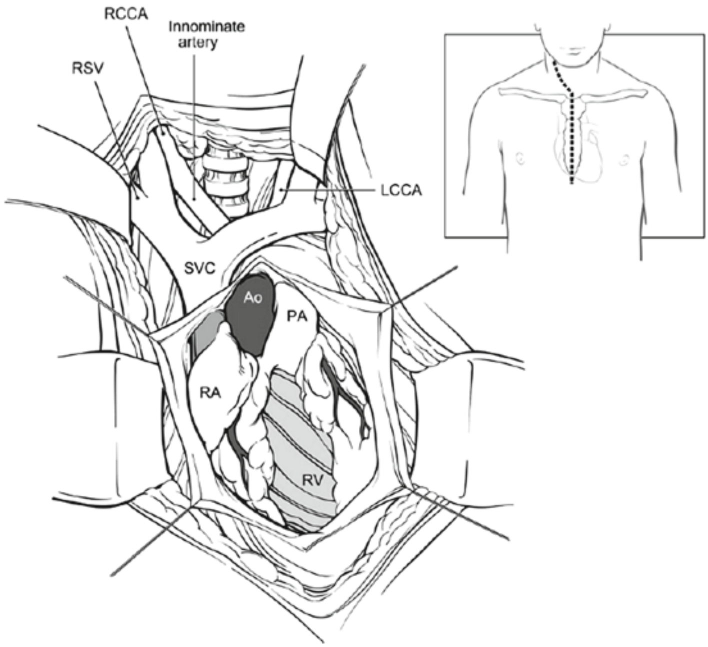

Fig. 13.5 Extension of the sternotomy incision into the right neck (*inset*) or supraclavicular area provides excellent exposure of the proximal right subclavian and right common carotid arteries. (Reprinted with permission from Meredith et al., Surgical Clinics of North America 2007;87:95–118)

to the posterior mediastinal structures, particularly the descending aorta. Dividing the adult sternum will require either a sternal saw or a Lebske knife. Know how to use both. Power tools may not be an option in the combat zone.

One Way In and Only One Way Out

If you were fighting a house fire you'd want to be able to get into more than just one room of the house – unless you were certain the fire was only in the one room and it had no chance of spreading. The same applies to incisions that limit your options of dealing with injury that is not confined to just one cavity. That's the trouble with the posterior lateral thoracotomy (Fig. 13.6) – if the fire is outside of the room you entered there is no door you can use to get to it. Certainly this incision provides the best exposure for repair of the lung and the only exposure with access to the posterior mediastinum and chest wall. This is the incision to use when you have a known injury that requires this approach for exposure (i.e. proximal left subclavian artery) and are relatively sure there is nothing going on in another body cavity or area of the chest. I am occasionally asked (usually by a resident) if we can rotate the patient's spine such that the abdomen is more accessible in case a laparotomy

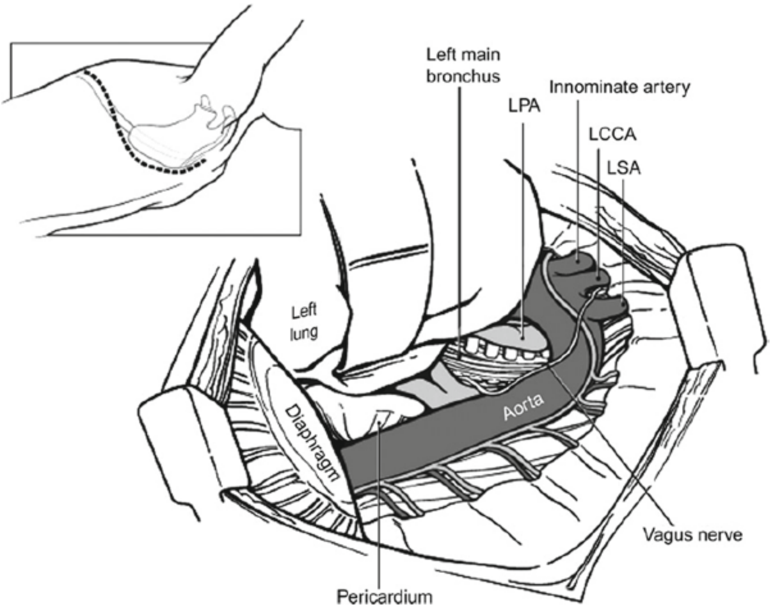

Fig. 13.6 Left posterolateral thoracotomy provides excellent exposure of the posterior mediastinum and particularly the aorta, esophagus, left common carotid (LCCA) and left subclavian (LSA) arteries. (Reprinted with permission from Meredith et al., Surgical Clinics of North America 2007;87:95–118)

is required. While an option, the patient will be positioned less than fully decubitus, supine, or both. So exposure in the chest or abdomen (or both) will be compromised. Because of the lethality associated with thoraco-abdominal injury requiring both laparotomy and thoracotomy – not to mention the questionable safety of rotating the patient's spine – this maneuver doesn't give me a warm feeling in *my* chest. So reserve the posterior lateral thoracotomy for the patient with a known unilateral injury complex requiring only a thoracic operation. One last caution – the bronchi have no valves so fluid will freely flow out of one lung and into the other. Rotating the patient to lateral decubitus position without a bronchial blocker or dual lumen tube is ill-advised. Keep your perspective – if the options of dual lumen tube or bronchial blocker are outside your scope of care and you are operating on a bleeding chest you should think again before risking drowning the patient in his own blood.

Variation on BLUF #6: The Costal Margin is Just Cartilage

The thoraco-abdominal incision is an option for gaining exposure in both the inferior thorax and upper abdomen. This incision is virtually never used for emergent exploration, but it may be the approach of choice for exposure of spine injuries in the T10–L1 area or complex thoraco-abdominal vascular repairs. The patient may be positioned either supine or in semi- or full lateral decubitus (Fig. 13.7). On the left, opening the diaphragm will provide exposure to the gastroesophageal junction, the structures in the posterior mediastinum including the spine, distal esophagus and descending aorta, and the abdominal organs in the left upper quadrant including the stomach, colon, spleen and kidney. The hemithorax, liver, vena cava, and kidney

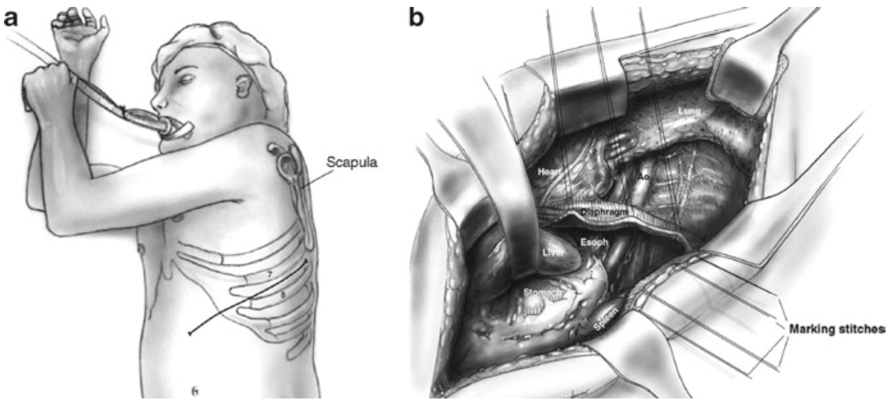

Fig. 13.7 Thoraco-abdominal incision through the seventh or eighth intercostal space and extended onto the anterior abdominal wall (**a**). Note the wide exposure provided of both thoracic and abdominal structures by opening the diaphragm (**b**). The diaphragm should be opened circumferentially preserving at least a 2 cm cuff attached to the chest/abdominal wall and use marking sutures to help with the subsequent repair. (Reprinted with permission from Gusani et al., Operative Techniques in General Surgery 2008;10:107–110)

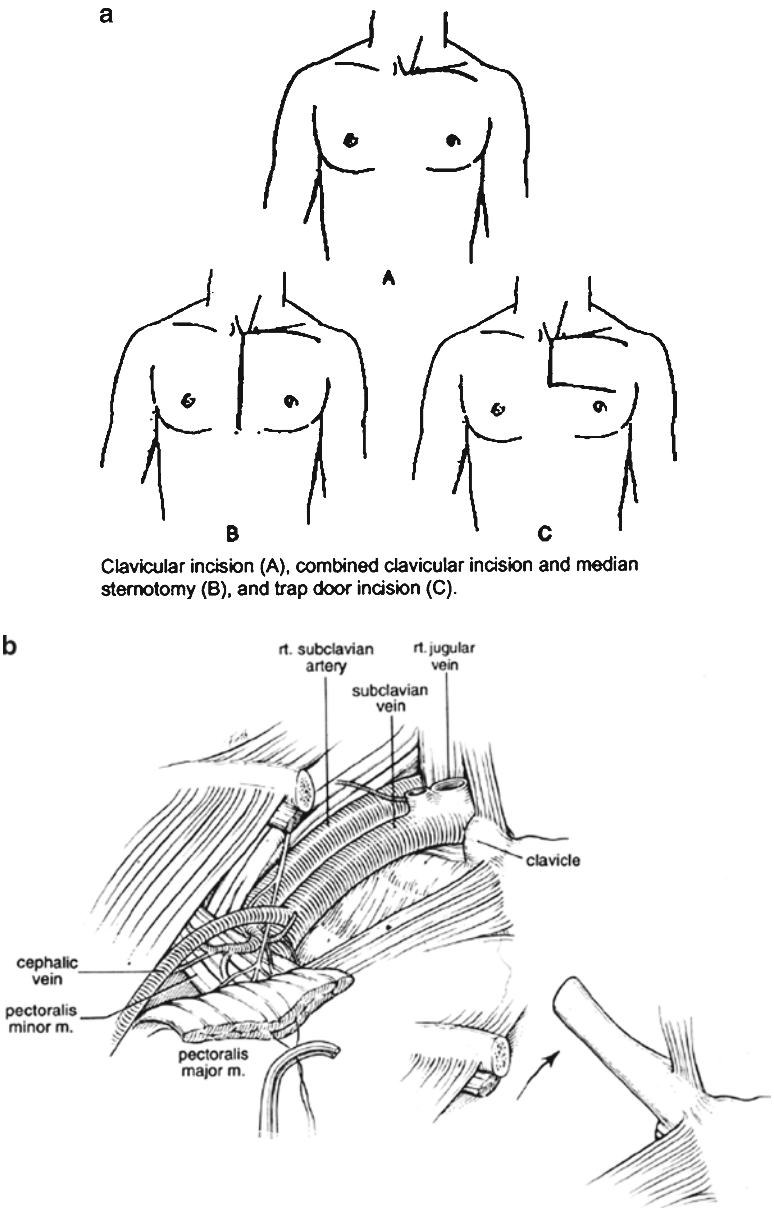

Fig. 13.8 (**a**) Variety of clavicular incisions and extensions for exposure at the thoracic inlet. (**b**) Resection or dislocation of the clavicle to obtain full exposure of the subclavian vessels. (Reprinted with permission from Demetriades et al., Current Problems in Surgery 2007;44:1–73)

can be simultaneously approached with a right thoraco-abdominal incision. The thoracic portion of the incision is made in the sixth or seventh interspace and then carried across the cartilage of the costal margin. A principle disadvantage of this incision is the pain associated with a costochondral nonunion and the potential for injury to the phrenic nerve – which is greatest for incisions involving the medial aspects of the diaphragm.

And So Goes the Clavicle…

As you may have figured out by this point, unlike the abdominal cavity there is no single incision or exposure that gets you everywhere you need to be in the chest. You will quickly realize this when you have a patient hemorrhaging from a difficult to expose structure or area. Another of these areas is the junction between the chest and neck or the chest and upper extremities – i.e. the subclavian vessels, proximal carotids, or even vertebral arteries. Do not let the skin or the clavicle stand between you and gaining adequate exposure and control. Figure 13.8a demonstrates several key clavicular incisions which can provide excellent exposure alone or in combination with a sternotomy. If the injured vessel or the site for obtaining control is behind the clavicle, then you can resect the midportion of the clavicle or dislocate and elevate the clavicle. This quickly turns a difficult exposure of these vessels into a "chip shot" (Fig. 13.8b).

Bottom Line

Don't confuse trauma and combat thoracic surgery with elective practice. Positioning is the key to utility and versatility. Keep your options open and be ready to extend, modify, or abandon an incision to get to the ABCs. Don't delay operative control or resuscitation for X-rays when the patient is trying to die on you. Recognize the lethality of the injuries that actually require a thoracic operation, particularly the thoraco-abdominal injury that requires operations in both the chest and the abdomen. Understand that you have a good chance of going into the wrong cavity first and can be fooled by chest tube output and abdominal examination. So again – *keep your options open!* Realize that there may be a few personal case series experts in combat thoracic trauma, but it's very, very unlikely that one is going to show up in your OR. You are going to be the best hope the patient has to survive the initial operation for a thoracic injury. If you do this long enough you will get some cases under your belt. But don't get overconfident. Add what you learn to our shared knowledge base. I wish you success in our noble cause to give the combat wounded the best opportunity for survival and recovery.

Chapter 14
Lung Injuries in Combat

Michael S. Meyer and Matthew Martin

Deployment Experience:

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BLUF Box (Bottom Line Up Front)

1. Blast mechanisms often create a deadly combination of blunt lung injury (contusion) and penetrating parenchymal damage.
2. Simple chest tube drainage has a much higher failure rate than in civilian lung injuries – be prepared to operate!
3. Damage control surgery and temporary closure is not only for the abdomen – use it.
4. You do not need a CT scan to diagnose these injuries or to determine if an operation is needed.
5. Lateral decubitus positioning and double lumen endotracheal tubes are time-consuming luxuries that most bleeding patients can't afford.
6. The only VATS in combat trauma is Very Aggressive Thoracic Surgery.
7. Avoid retained hemothoraces by doing it right the first time – this means in the OR.
8. Pulmonary tractotomy is a great technique – and you will almost never use it. Most combat lung injuries will require anatomic or non-anatomic resection.
9. Review your thoracic anatomy and surgical techniques – consulting Cardiothoracic Surgery is usually not an option.
10. Don't forget about air embolus – it can kill you patient faster than hemorrhage.

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In massive insults to the organism, treat the patient for the insult, without waiting for the response to the insult.

Mark Ravitch (1910–1989)

This chapter is based on two universal truths in combat trauma: (1) You WILL be faced with severe thoracic injuries that require quick decisions and operative intervention, and (2) Most of you are not fellowship trained cardiothoracic surgeons and will not have one immediately available. You may be given the advice that "damage control in the chest is just like damage control in the abdomen" – don't be lulled into complacency. Losing the comfort level and deep understanding of anatomic relationships that you have in the abdomen makes combat chest surgery an entirely different and often unforgiving adventure. There are two things you can do to set yourself up for success in thoracic trauma – Prepare and Practice. Prepare by reviewing any anatomy text or surgical atlas to get familiar with the critical structures and relationships as well as basic operative techniques. Practice by either scrubbing in to elective thoracic cases if you can, or by reviewing common thoracic injury scenarios and how you will handle them. Do not forget the most basic lesson of the soldier – **"you will fight as you train."**

Surgical Approach ("You Can't Get There from Here")

The previous chapter describes in detail how you should approach chest injuries in combat trauma and the choice of incisions. The main point that cannot be repeated often enough is that you should almost always be approaching these injuries through an anterolateral thoracotomy or median sternotomy, with the patient supine. Inexperienced trauma surgeons use "elective" surgical approaches aimed at maximizing ease and exposure at the expense of flexibility and options. A good combat surgeon will accept less than perfect (although always adequate) exposure to maintain the maximal amount of flexibility and options. If you break this basic rule then you will inevitably end up with the patient in a lateral decubitus position when you realize that the bleeding is actually coming from the abdomen, the mediastinum, or the other side of the chest. You can do everything you need to do through an anterolateral thoracotomy – just make sure your incision is long enough and you have adequate self-retaining retraction. Rapid entry into the chest can be obtained with one or two aggressive swipes of the scalpel through skin, fat, and muscle followed by wide opening of the remaining intercostal muscle fibers and pleura using heavy scissors. The best, and most underutilized, maneuver to improve exposure is to extend your skin incision medially for 5–10 cm onto the opposite chest and divide the sternum. Now that you're there, establish your priorities and get to work.

Damage Control Principles in the Chest (This Ain't The Abdomen)

Just like a combat trauma laparotomy, a damage control approach should be your default when operating on major traumatic lung injuries. Do what needs to be done immediately and what the patient will tolerate, and then get out to finish the fight another day. But that is where the similarities to abdominal damage control end. In the abdomen the only *immediately* life-threatening concern you need to focus on is controlling hemorrhage. This is usually not the case in the chest. Tension pneumothorax, cardiac tamponade, arrhythmias, refractory hypoxia or hypercarbia, and the dreaded air embolus are all quick and silent killers that need to be on your mind and rapidly addressed or prevented. Close coordination with your anesthesia provider in these cases is of the utmost importance, particularly in the setting of lung injury. Do not waste time trying to get a double lumen endotracheal tube or bronchial blocker in perfect position before starting the operation – you will usually lose much more than you gain and it can wait until you have bleeding controlled. Some simple manipulations of the tidal volume and respiratory rate or positioning of the endotracheal tube (i.e. advanced to right mainstem) can make your life a whole lot easier and get the inflated lungs out of your way.

Just like in the abdomen, hemorrhage control is goal number one. Packing is not the first maneuver, particularly when the chest is full of blood! Rapidly scoop out the clot with your hands and then use some dry lap pads and suction to remove the remainder of the pooled fluid. Now assess the hemorrhage and determine if the bleeding can be easily controlled with manual compression or clamping – if so, proceed with definitive control. If you have large volume hemorrhage or bleeding from multiple sites then go ahead and pack the cavity, make sure your anesthesia provider is catching up and ready for more bleeding, and then begin pack removal and hemorrhage control. If the volume of bleeding is too great to allow for packing to assist in visualization, use your fingers as a clamp to occlude the main pulmonary artery and vein at the hilum while an assistant works on using sponges and a sucker to clear out the blood. If no assistant is available a large vascular clamp can replace your fingers to accomplish the same goal. At this point you can gradually release the hilar vessels to better localize the bleeding source. A kidney pedicle clamp is common in the field, although a larger, more gently curved, and less traumatic clamp if available is a better choice. Adequate exposure, retraction and packing of lung, and strong suction are your best allies for localizing the bleeding and obtaining control.

In addition to hemorrhage, you must also consider and address the several other quick killers listed above. Opening the chest has removed the possibility of any tension physiology on that side, but don't forget about the contra-lateral chest. Be liberal about putting in a chest tube on the other side to rule out significant bleeding or pneumothorax. If you are using a median sternotomy, you can incise both pleura and open them widely with your fingers. If you are faced with life threatening hypoxia or hypercarbia, then quickly look for a potentially treatable source such as a massive air leak from lung parenchyma or an injury to the proximal airways. Maximize ventilation of the normal lung by advancing the endotracheal tube to mainstem the opposite airway, placement of a bronchial blocker, or a double lumen tube. All of these take some time so try to control the air leak by clamping the lung or airway proximal to the site of injury. This may entail clamping the entire lung hilum for a very proximal injury, even using your fingers as a clamp initially as described above. Alternatively, if you have good exposure and visualization you can rapidly suture the injury and return later for definitive repair. For proximal airway injuries, use absorbable suture such as PDS or Maxon in case your rapid repair turns out to a durable one.

Don't forget about air embolism! It is a relatively common and often unrecognized killer in patients with a pulmonary laceration who have the potential for air entry into the pulmonary venous system. There are several things you can do to minimize the chance of an air embolus: rapid control and compression of the injured lung segment, proximal pulmonary hilar clamping, low pressure ventilation until the injury is controlled, and submerging the injured area under saline. If your patient experiences sudden cardiac decompensation with no other obvious source then air embolism should be assumed and you can follow the management principles outlined in the next section.

Performing a damage control closure of the thoracic cavity can be more complicated than the abdomen. Simply packing the cavity and closing is usually not an option, particularly when there is bilateral lung injury and the patient won't tolerate complete compression of one lung. Other factors you must consider are creating a tension pneumothorax or tamponade by closing the cavity without adequate drainage, and maintaining some degree of normal respiratory or chest wall mechanics. In any chest closure, you must leave adequate large bore chest tube drainage. In general, nothing less than two 32F tubes is adequate after a trauma thoracotomy, especially if transport out of theater is in the patient's near future. My preferred temporary closure is using a large monofilament suture incorporating muscle, fascia, and skin in an en masse running and locked closure. This will create a tight closure and control bleeding from the wound margins better than a skin-only closure. Rapid skin only closure can also be performed with a running suture, staples, or towel clips. Alternatively, the wound can be closed without suture by manually holding the wound edges together and applying a large Ioban dressing. Ioban is also useful in a complex incision that doesn't come together adequately and there is concern for air leak. Don't forget bleeding from your incision! The chest wall musculature, intercostals vessels, and internal mammary arteries will all bleed significantly if not properly assessed and controlled before leaving the OR.

Pneumothorax and Hemothorax

Pneumothoraces are relatively common in combat trauma, although the isolated pneumothorax without an associated hemothorax or other significant chest injury is much less common than in civilian trauma. Physical exam diagnosis is often difficult, particularly in the noisy and chaotic trauma bay. You should familiarize yourself with the simple and highly reliable technique for ultrasound diagnosis of a pneumothorax (see Chap. 6) as you may not have x-ray immediately available. You will see many patients arrive with needle catheters placed in the field – these are often placed unnecessarily and frequently never actually penetrate into the thoracic cavity. You are not automatically obligated to place a chest tube – assess the patient and if their pulmonary status is stable, remove the needle and do your ultrasound or chest x-ray. If there is associated blood, then a large bore chest tube placed in the standard fashion (posteriorly to the apex) is appropriate. If it is an isolated pneumothorax then you are often better off placing a smaller tube in a more anterior position, and guiding it along the anterior chest wall to the apex.

Hemothorax in combat injuries should raise your concern for associated severe intra-thoracic injuries, continued bleeding, and the possible need for an operation. While the majority of civilian hemothoraces can be managed with tube thoracostomy only, we have found that to be much less successful in the combat setting. Always remember the limitations of your surroundings – the trauma bay in any forward deployed facility is a highly contaminated, crowded, and unsterile environment that is not optimized for procedures. You will also not have VATS available to easily manage problems like a retained hemothorax or empyema. If your patient has a significant hemothorax that requires chest tube drainage, then the best place to do that is in the controlled and more sterile environment of the operating room. If you make your incision slightly larger than usual (3 cm is fine) you can pass a large suction catheter into the chest to thoroughly evacuate the blood and perform large volume irrigation prior to placement of the chest tube. This way you are also prepared to rapidly get into the chest for persistent or large volume bleeding, massive air leak, or other injuries requiring surgical intervention.

Lung Parenchymal Injuries

Injury to the lung parenchyma will be the most common problem you will face when operating in the chest. Fortunately it is usually not difficult to quickly identify the exact area of injury and to gain at least temporary control of bleeding. The injured area will typically demonstrate continuous low volume bleeding and will likely also have a visible or audible air leak. The first instruments you should be sticking into the chest to control bleeding should always be your hands. Simple bi-manual pressure on the injured area is usually sufficient to control bleeding and will also improve handling by compressing air out of the lung tissue. It may also be helpful to have the anesthesia provider lower the tidal volumes or advance the endotracheal tube to mainstem the opposite bronchus to facilitate exposure. Even with both lungs being fully ventilated, you can collapse the ipsilateral lung by applying gradual and continuous pressure during exhalation with laparotomy pads and then maintain the exposure with a self-retaining retractor.

Normal lung tissue is relatively fragile, so injured lung tissue is extremely easy to tear or disrupt with improper or overly aggressive handling. Use only your hands initially to expose the lung and compress the area of hemorrhage. Grasping and retracting the lung is aided by using a small lap pad or gauze for traction, but do not pull the tissue perpendicular to the injury as this will enlarge the parenchymal disruption and worsen the air leak. Duval lung clamps are available in the field and can be a useful adjunct when manipulating the lung. Additionally, using Duval lung clamps to temporarily oppose injured lung tissue can control the air leaks initially and free your hands to continue exploring the chest and deal with more urgent matters.

After you have adequately controlled hemorrhage and assessed parenchymal injuries, you must decide on the most expedient and complete method to control air leaks while at the same time preserving lung tissue (see Fig. 14.1). Young healthy soldiers will tolerate a significant amount of lung tissue loss, so do not be worried about large stapled wedge resections. The choice of staple load will depend on the thickness of the tissue to be divided; however staples with a depth of 3.5–3.8 mm in a linear stapler (this translates into a blue or gold Ethicon GIA load) are good choices that work in all situations. For missile wounds through the lung tissue, a stapled tractotomy (Fig. 14.2) may be an adequate method to initially control air leaks as well as get to the source of bleeding. One arm of the stapler is placed through the missile tract and the lung above the tract is divided. You may need more than one load to accomplish the above goals. Inspect the opened missile tract and ligate large vessels and air leaks with suture as needed. Pneumonorraphy, or over sewing of the entrance and exit wounds, should be avoided. You may not have an appropriate stapler or staple loads, so an alternative is to use clamps to secure and divide the tract (Fig. 14.3).

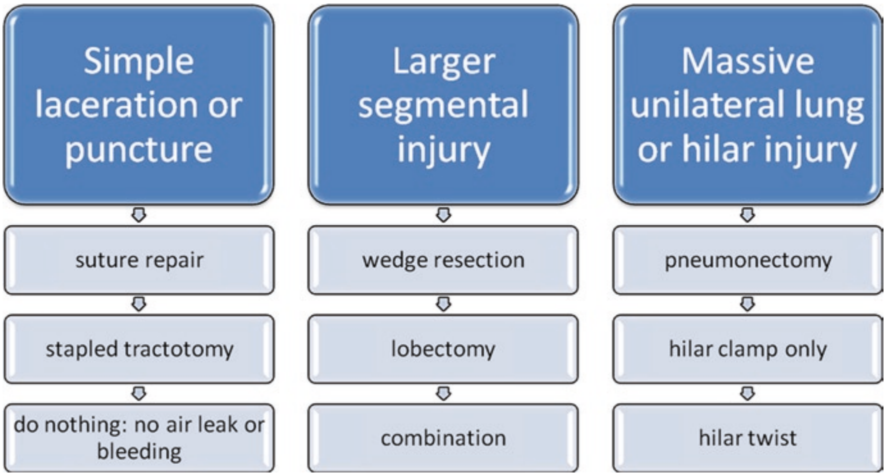

Fig. 14.1 Diagram outlining operative management strategies to consider based on the type and degree of lung injury

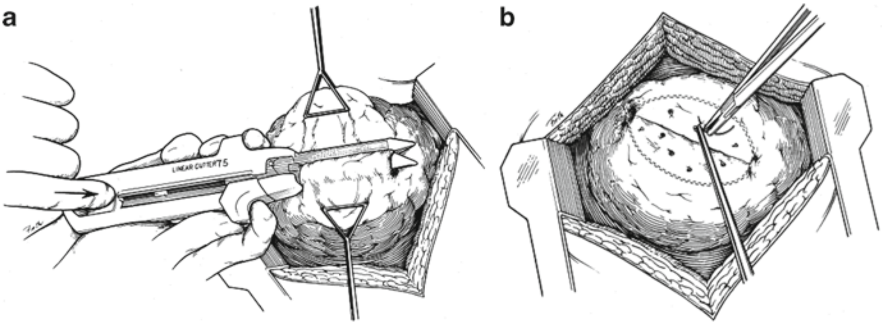

Fig. 14.2 Stapled tractotomy for a penetrating through and through lung injury. A linear stapler is passed through the defect and fired (**a**), opening the tract and exposing the underlying injured lung tissue. Direct suture repair of bleeding and parenchymal disruption can then be performed (**b**). (Reprinted with permission from Asensio et al., J Am Coll Surg 1997;185:486–487)

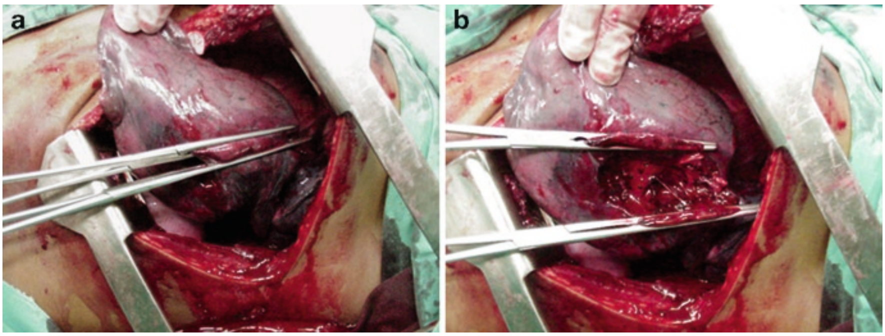

Fig. 14.3 Pulmonary tractotomy performed with large non-crushing clamps placed through the defect (**a**) and then sharp division of the tract to expose the underlying injured lung (**b**)

Do not expect a stapled tractotomy and a couple of stitches to be the answer for most combat type injuries. Unlike civilian low-velocity injuries, a high velocity missile or multiple fragments will deform or devascularize the tissue so severely that a tractotomy is not an option. For most peripheral injuries, the damaged lung can be wedged out with a stapler. Manually compress the area to be resected during exhalation to flatten it for placement of a linear stapler. Do not buttress the staple line with suture as you will likely make things worse. Some residual air leak is acceptable and expected. However, if a significant amount of tidal volume is being lost during ventilation, there is a tremendous observable air leak in the operative field, or the chest tubes placed are not adequately draining the pleural space as evidenced by a persistent pneumothorax on a post-operative chest x-ray, additional lung resection may be necessary. In the operating room, place water (sterile water works best, saline is okay) in the chest to try to localize the majority of the remaining air leak. A large volume air leak that can be isolated to a particular lobe that cannot tolerate more staples will likely need a formal lobectomy. Do not leave your patient with a massive broncho-pleural fistula in the name of preserving an already damaged lobe – he will be much better off with a little less lung than with ongoing air leaks and contamination.

When operating in a controlled environment, lobectomy is a precise and deliberate operation that can be challenging. Without a solid idea of normal anatomy and the major variations that can be seen from one side to the other, a trauma lobectomy can quickly become a frustrating operation. While a thorough anatomical review is beyond the scope of this chapter, there are several points that will help you successfully complete the case. As a general rule when approaching the pulmonary arteries, be gentle as this artery does not have the same characteristics of arteries in the systemic circulation due to the low pressure of the pulmonary arterial circulation. They tear easily, they do not hold suture well, and have a tendency to dissect when handled roughly. The pulmonary artery branch vessels are especially fragile and can be transected by suture that is snugged down too tightly in the heat of battle. If you decide to individually suture ligate the branches of the pulmonary artery, be sure to use stick ties in addition to your ligatures. If a pulmonary artery is bleeding after being tied or stapled, avoid the urge to continue placing ligatures or stick ties. Remember this is a low pressure system so surgicel or a similar topical hemostatic agent should be placed with a sponge over the area of concern initially; this type of bleeding almost always stops without further intervention. The pulmonary veins are much more forgiving and will tolerate some manipulation. When possible, use linear staplers with a vascular load for all pulmonary arteries and veins; it is a quick and reproducible technique. If space seems limited in the chest for using standard linear staplers, consider using an endoscopic linear stapler if available. They can be placed through chest tube sized holes to allow for a better angle of approach to vascular structures.

The Pulmonary Hilum: Tread Lightly

Hilar anatomy is very predictable and constant between the two thoracic spaces (Fig. 14.4), while lobar and segmental anatomy is highly variable. As you look into the chest while standing at the patient's injured side, which will likely be through an anterolateral thoracotomy, reflect the lung posterior and laterally (toward yourself) so that branches of the pulmonary vein can been seen. They are usually overlying the pulmonary artery and usually must be divided first. This relationship is especially critical when removing the upper lobe as these two structures may be so closely associated, it will be difficult to distinguish them in a bloody field. The bronchus will be slightly deep to the pulmonary artery from this aspect. While this is great exposure for a pneumonectomy, additional manipulation of the lung superiorly and inferiorly will allow exposure of vascular structures to the individual lobe. As the lung is mobilized, retraction of the lobe needing resection anteriorly (away from you) will facilitate the dissection.

A good place to start with any lobectomy is with division of the pulmonary ligament and incision of the pleura surrounding the lobe to be removed; both of these

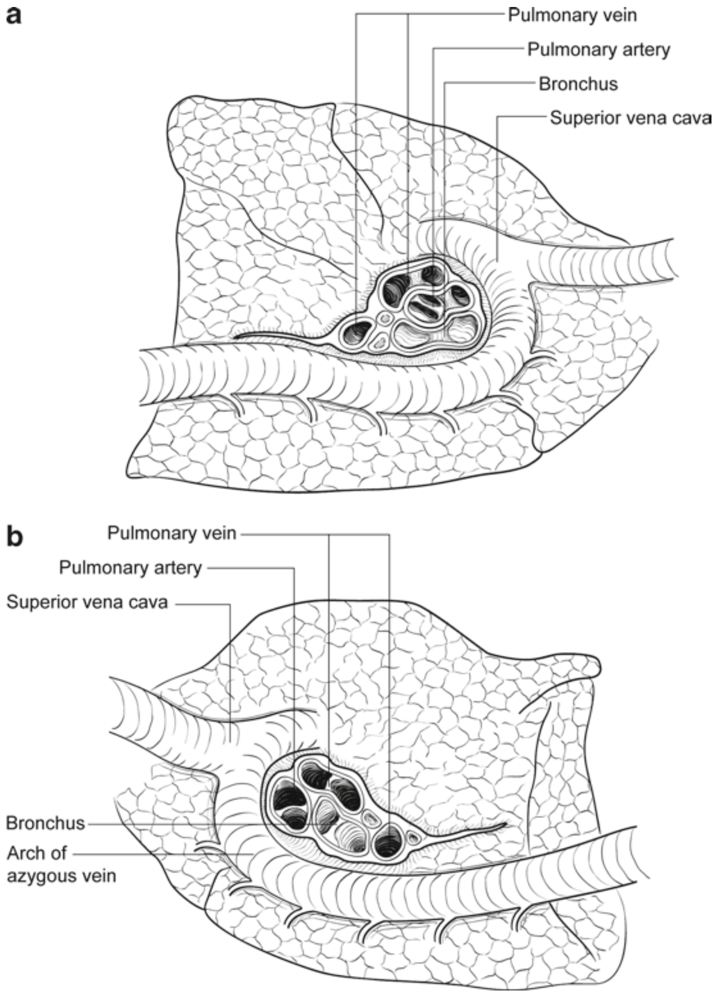

Fig. 14.4 Diagram of the pulmonary hilar anatomy for the *left* (**a**) and *right* (**b**) lung as seen from an anterolateral thoracotomy approach

maneuvers allow for better lung mobilization. Identifying the pulmonary artery deep in the major fissure is the easiest method to begin identification of pulmonary artery branches. Umbilical tapes and Rummel tourniquets are handy to have in order to isolate arterial branches you are not initially certain about or as a way to help guide the anvil of a stapling device. An umbilical tape is also useful when completing a fissure. After using a combination of your fingers and a kidney pedicle clamp to determine where the fissure should be completed, pass an umbilical tape through the space you created to guide the anvil of your stapler. Exposure and identification of key structures is aided by alternating your exposure dissection between an anterior and posterior approach – once the anterior dissection is done

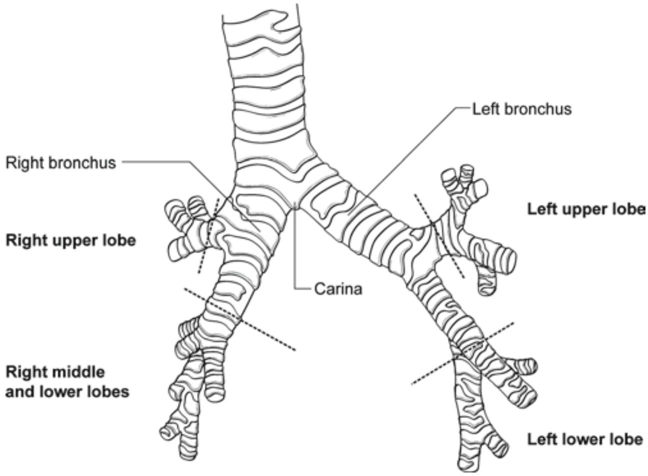

Fig. 14.5 Diagram of the basic bronchial anatomy, with dotted lines indicating the line of bronchial division for a formal lobectomy

or cannot proceed any further safely, flip the lung away from you and approach the lobar hilum from the posterior side. An understanding of the basic bronchial anatomy is particularly critical for identification and control of the correct bronchial structures (Fig. 14.5).

When operating on the right side, do not go through a great effort to spare the middle lobe, especially when removing the upper lobe as they share venous drainage from the superior pulmonary vein and the minor (or horizontal) fissure is usually incomplete. The middle lobe is easier to preserve when removing the lower lobe as the major (or oblique) fissure is often well-formed. As the pulmonary artery is exposed in the major fissure, look for a posterior ascending arterial branch to the posterior segment of the upper lobe. This will need to be divided in addition to the branches off the superior pulmonary trunk when removing the upper lobe. When the lower lobe is being resected, care must be taken to preserve this branch as it is easy to inadvertently divide when completing the major fissure. An additional technique to assist in exposing structures for procedures on the right upper lobe is to divide the azygous vein.

As on the left side, be aware of pulmonary artery branches supplying the upper lobe as the main artery travels through the interlobar fissure. Specifically, there may be one or two lingular branches as well as a smaller artery to the posterior subsegment of the anterior segment of the upper lobe. These three vessels may also exist as a common trunk. Vessels to the lower lobe should take off from the pulmonary artery directly opposite from the lingular branches. At times the bronchus to the superior segment of the lower lobe must be divided separately. If you have a large air leak after a left lower lobectomy, look for this portion of the bronchus to ensure it is secured.

Pulmonary Hilar Control

As with all pulmonary injuries that present to the surgeon with a field of frothing blood, it is imperative to gain immediate control of hemorrhage with techniques described above and elsewhere in this book. If you have adequately controlled bleeding and air leaks from the lobes and you are still having difficulty, look centrally. You will be faced with deciding if the injury is vascular, tracheobronchial, or both. You can gain immediate and rapid hilar control with your hand without any mobilization – simply retract the lung laterally and encircle the hilar structures which are tethering the lung to the mediastinum with one hand (Fig. 14.6). This will gain time for you to do a little mobilization and switch out your hand for a vascular clamp. Incise the inferior pulmonary ligament for 2–3 cm to allow full retraction of the inferior lobe, but beware that further division will lead into the inferior pulmonary vein. You can now pass a large straight or slightly angled vascular clamp across the proximal hilum and clamp tight enough to compress both the bronchus and the vessels. An alternative technique that has been described is the "hilar twist," which is accomplished by dividing the inferior pulmonary ligament and then rotating the lung to twist the hilum and cut off pulmonary blood flow (Fig. 14.7). The lung is secured in the twisted position by placing packs

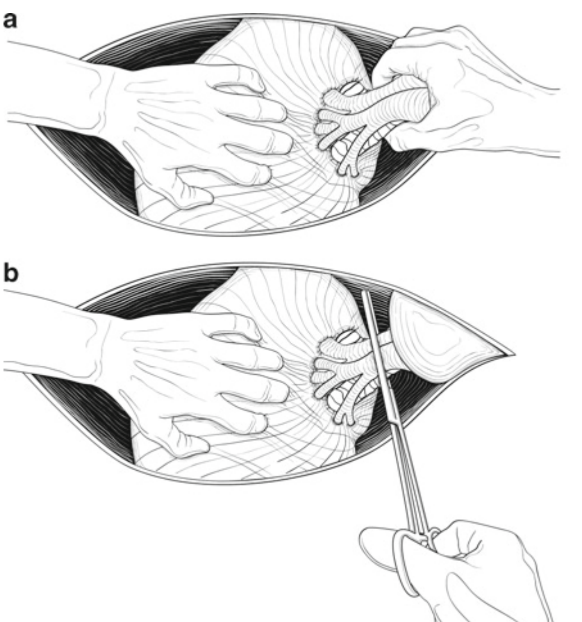

Fig. 14.6 Approach for obtaining manual control of the pulmonary hilum, followed by placement of a vascular clamp if necessary

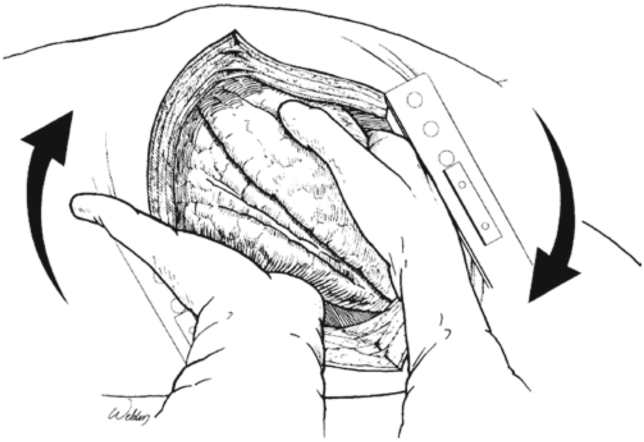

Fig. 14.7 Hilar twist maneuver for control of pulmonary hemorrhage. The inferior pulmonary ligament is released and the lung is then twisted clockwise 180° (reprinted with permission from Wilson et al., Am J Surg 2003;186:49–52)

superiorly and inferiorly, and then a damage control closure can be performed. Formal pneumonectomy can then be completed at a later time if needed.

Pneumonectomy (It Is Not a Dirty Word)

A pneumonectomy in the trauma setting carries a high associated morbidity and mortality, due to both the physiologic impact of the procedure as well as the severity of injuries. The key to a successful outcome in this scenario is making the decision early and performing the procedure rapidly and in concert with your anesthesia provider. Too often the pneumonectomy is performed as a "last-ditch" measure after an hour or two of failed attempts at lung salvage. Typical indications for a pneumonectomy will be massive multi-lobar injury, complex hilar injuries, or any significant injury that will require complex reconstruction in an unstable patient.

The only reason not to do a stapled pneumonectomy in the trauma setting is that you don't have a stapler available. Simple en masse ligation of the hilar structures should never be attempted – you will not be able to adequately compress the vascular structures due to the rigidity of the bronchus. This may be immediately obvious, or may manifest as sudden exsanguinating hemorrhage once the patient is better resuscitated and the blood pressure increases. There are several techniques to be aware of to perform an expedient trauma pneumonectomy. If you can gain control of the hilum with a large clamp or your hand, a stapled pneumonectomy is very simple and fast (Fig. 14.8). Pass a large TA stapler (at least 60 mm, possibly a 90 mm) through the space you created to encompass all vascular and bronchial structures. If you can safely pass a second stapler to create a doubled stapled pneumonectomy, this may make for a better long term result. Make sure you cross the "blood-brain

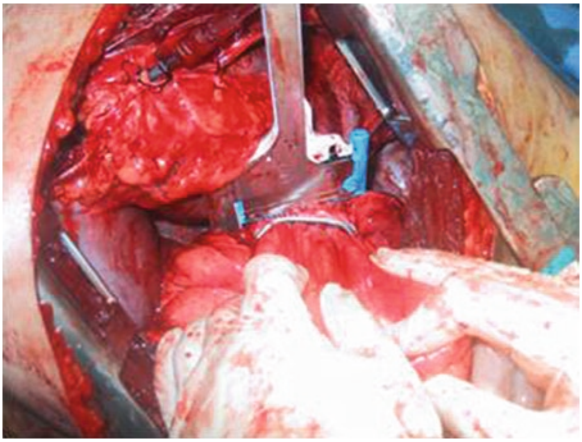

Fig. 14.8 A trauma pneumonectomy can be rapidly performed by en-masse stapling of the hilar structures once control has been obtained. One or two staple lines are applied and the hilum is then sharply divided

barrier" and communicate with the anesthesia providers at the head of the table! When you clamp the hilum you will not only take one lung out of duty, you will create massive right heart afterload which is often not well tolerated. We would recommend starting a dobutamine infusion with hilar clamping to improve right heart contractility and decrease the pulmonary artery pressures, and have additional vasopressors ready to go as needed. The patient will also likely require continued volume support as well as a high fraction of inspired oxygen and careful ventilatory management to avoid undue barotrauma to the remaining lung.

A large chest tube should be placed after pneumonectomy and placed to water seal, not suction. You want to ensure the mediastinum is balanced; if you find the mediastinal shift to the operated side is great enough to cause hemodynamic instability, introduce air into the empty pleural place and check your results with a chest x-ray. If you are unsure pneumonectomy is necessary and can get the patient out of the OR without this, pack the chest as necessary, make a temporary closure and plan to bring the patient back when better resuscitated. If a pneumonectomy is still indicated, a more controlled operation can be planned with deliberate dissection of the hilar structures, better securing of the bronchus, and less chance of injuring surrounding structures such as the phrenic and vagus nerves and esophagus. In several cases of ongoing lung hemorrhage that could not be easily controlled in a far-forward setting, topical hemostatic agents or dressings have been used along with packing to control bleeding and get the patient to the ICU or to a higher level of care. Figure 14.9 shows a granular hemostatic (QuikClot) which was applied by a Forward Surgical Team and achieved complete hemostasis until the patient reached a level III facility. Quick thinking and using all of the tools at your disposal will save lives in thoracic trauma.

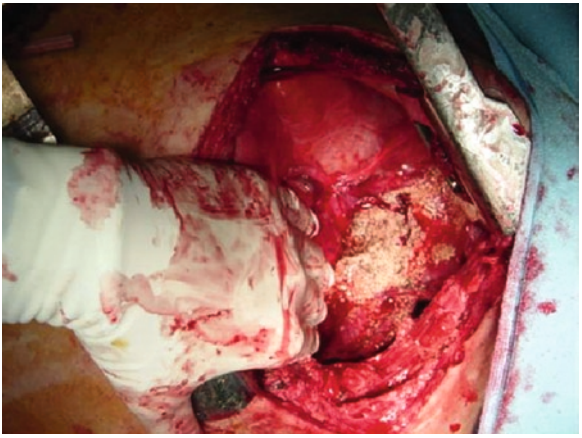

Fig. 14.9 Damage control thoracotomy with application of QuikClot topical hemostatic granules to diffusely bleeding area of lung and chest wall

Air Embolism

As mentioned above, air embolism is a quick and often unrecognized killer in the setting of major bronchial disruption with associated pulmonary vein injury. It can occur in both penetrating and blunt trauma, which includes blast injury. The best chance for survival is early control of the source of the air. A high index of suspicion is critical as associated injuries in the multi-trauma patient may have similar symptoms, which includes profound hypotension and sudden cardiac arrest. Remember that air entrained into the injured pulmonary veins will enter the left side of the heart, not the right. This makes it a very different entity that the usual air embolism seen with inadvertent air injected into a peripheral or central vein. A large amount of air can be tolerated on the right side, but an extremely small volume of air on the left side can be deadly. This is due to the impact of air bubbles entering the coronary arteries (as little as 0.5 ml into the left anterior descending artery) resulting in acute occlusion and cardiac arrest. Larger amounts of air may also cause significant neurologic injury if it reaches the cerebral circulation (Fig. 14.10).

The most critical point in management has been mentioned: control the air leak as quickly as possible by placing clamps across the injured lung parenchyma. If this is unsuccessful, clamp the hilum as expeditiously as possible. If there are no clamps immediately available, use your hands to compress the lung tissue or compress the hilum. You can also fill the chest with saline while awaiting the tools you need. Simultaneously, the anesthesia provider should be lowering airway pressures, attempting to exclude the injured lung by advancing the endotracheal tube to the uninjured side, placing the patient in steep head down position, and starting pressors and fluid to maintain blood pressure. As the surgeon, you

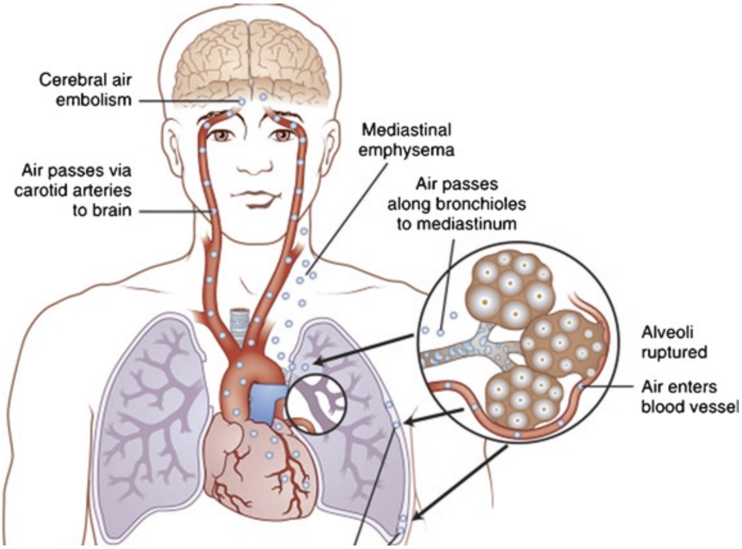

Fig. 14.10 Air embolism to coronary and cerebral circulation can occur with traumatic disruption of alveoli and pulmonary veins resulting in air entry into left ventricle via pulmonary venous return (modified with permission from Wilderness Trauma, Auerbach P. editor, Mosby Publishing, New York 2007)

must tell the anesthesia provider to do these maneuvers. At this point you will likely be resuscitating an arrested heart. If the left chest is already opened, clamp the descending aorta to help with hypotension and also help to flush the air through the arterial system. This should only be attempted if the air leak is controlled or you risk disseminating air to the rest of the organ systems. Additionally, open the pericardium and aspirate the left ventricle. If you have the right chest opened, divide the sternum, complete a clamshell incision, and proceed with the above maneuvers. The only option at this point is to continue to support the patient with open cardiac massage, defibrillation with paddles applied directly to the heart, and intracardiac pressors as needed. If you are successful in supporting the patient through this, consider leaving your clamps on the lung tissue in place, removing the aortic cross clamp, and temporarily closing the patient before undertaking a major pulmonary resection.

Evacuation

The medical evacuation process is covered in more detail elsewhere in this book. For the patient with a major lung injury, you can expect significant challenges in the postoperative hemodynamic and ventilatory management. You most likely will not have access to any advanced support modalities such as cardiopulmonary bypass, high frequency ventilation, or inhaled nitric oxide. When you max out your standard ventilator settings and have 100% inspired oxygen running, you have nowhere to go and no room for any further deterioration. You must make evacuation arrangements for these high-risk patients as early and rapidly as possible. You may have a very narrow window of stability during which they could tolerate a transport ventilator to get them to a higher level facility with access to these salvage modalities. An alternative developed during the current conflicts in Iraq and Afghanistan is the Acute Lung Rescue Team (ALRT), based at Landstuhl Regional Medical Center. This group can bring advanced ventilatory modalities and a critical care transport team to the combat theater to evacuate patients who would otherwise not survive standard medical evacuation. Consult them as early as possible to avoid any delays in assembling or transporting the team where they are needed.

Final Points

Pulmonary injuries require the surgeon to operate outside their usual comfort zone on an injury pattern that can cause the rapid demise of the patient if not quickly addressed. There is no time to spare when addressing these injuries so be prepared prior to seeing one. Know what clamps, chest tubes, and staplers are available immediately upon your arrival at a new duty station, combat support hospital, or FST and replace or order what you think is appropriate. Fast thinking during these cases and control of your environment to include addressing the actions of the anesthesia provider will save lives. Do not let them delay your saving of the patient with one more IV or another attempt at a bronchial blocker. You do not need a lung to be deflated in order to fix it. Remember that the heart and lungs are like Siamese twins: what affects one organ will affect the other. Expect that the necessary and rapid control of bleeding from the hilum may put your patient in right heart failure and be prepared to handle such situations postoperatively. Your best tool to gaining initial control is your hands, so don’t forget to use them.

Chapter 15
Diagnosis and Management of Penetrating Cardiac Injury

Keith A. Havenstrite

Deployment Experience:

Keith.A. Havenstrite 14th Combat Support Hospital, Bagram, Afghanistan, 2006

BLUF Box (Bottom Line Up Front)

1. Suspect penetrating cardiac injury (PCI) in patients with penetrating neck, chest and upper abdominal injury.
2. You must promptly diagnose and treat PCI to prevent loss of life.
3. If your FAST exam is positive for pericardial fluid, you must evaluate for hemopericardium with a pericardial window or sternotomy.
4. Observing hemodynamically stable patients with suspected PCI and pericardial fluid on FAST may result in sudden, irreversible deterioration and death even days after injury.
5. Notify the anesthesia provider before you manipulate the heart.
6. Volume resuscitation and Trendelenburg position can help to minimize the decrease in blood pressure that cardiac manipulation produces.
7. Injuries of the atrial appendages, right atrial free wall, aorta and vena cava may be suitable for the application of a partial occluding vascular clamp for hemostasis during repair.
8. There is no contraindication to the use of pledgets when repairing any great vessel or external cardiac injury.
9. All ventricular lacerations should be repaired using pledgeted suture.

The heart is the chief mansion of the soul, the organ of vital capacity, the beginning of life, the foundation of vital spirits… the first to live and the last to die.

Ambrose Pare (1510–1590)

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Introduction

Although relatively rare, you will likely be exposed to penetrating cardiac injuries much more frequently in the combat environment than in the civilian trauma environment. The clinical presentation of patients with penetrating cardiac injury varies widely and can be divided into five categories: lifeless, critically unstable, cardiac tamponade, thoraco-abdominal injury and benign presentation. Regardless of the patient's condition at presentation, penetrating cardiac injury is life-threatening. You must diagnose and treat these injuries before clinical deterioration and death ensues.

Diagnosis of Penetrating Cardiac Injury

Suspect PCI when a patient presents with penetrating injury to the chest, neck and/or upper abdomen. Clinical concerns dictate the studies and techniques you use to diagnose PCI. For example, the patient's clinical presentation may necessitate immediate resuscitative thoracotomy during which direct visualization will determine the presence or absence of hemopericardium indicating an intra-pericardial injury and possible PCI. In the more stable patient an AP chest radiograph may demonstrate missiles or fragments over the cardiac silhouette that will increase your suspicion of a PCI (Fig. 15.1). However, the sensitivity and specificity of the chest radiograph are low in the diagnosis of PCI. The Focused Assessment with Sonography for Trauma (FAST) exam is a quick, portable, and sensitive method to detect pericardial fluid that may indicate hemopericardium and PCI. Hemodynamically stable patients may have a CT of the chest, abdomen and pelvis. In patients with penetrating wounds suspicious for PCI, pericardial fluid identified on CT or FAST exam must be evaluated by either sternotomy or with subxiphoid pericardial window or trans-diaphragmatic pericardial window during laparotomy. The patient's clinical condition directs your actions to diagnose PCI.

For patients with penetrating injury who present with no signs of life but had recordable vital signs at any point after injury, obtain a definitive airway and perform immediate resuscitative anterolateral thoracotomy, in the trauma bay, through the left fifth intercostal space (just inferior to the male nipple). Pericardial incision will facilitate diagnosis of PCI. If you diagnose hemopericardium, extend your thoracotomy across the sternum to complete a clamshell incision in the right fifth intercostal space. You will then have the exposure you need to open the pericardium and repair the PCI (Fig. 15.2).

For critically unstable patients, place a definitive airway and bolus with isotonic fluid or blood. If hemodynamics improve and FAST exam shows pericardial fluid, move immediately to the operating room for definitive management with median sternotomy. If the patient has no clinical improvement, perform resuscitative thoracotomy in the trauma bay as described above.

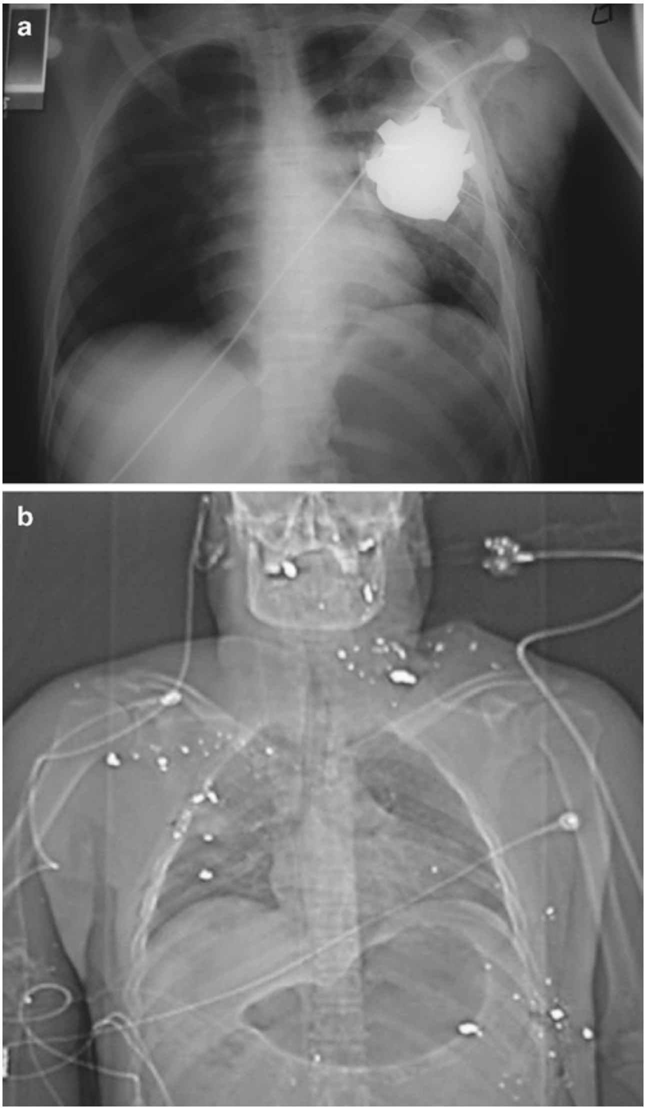

Fig. 15.1 Chest X-rays from combat missile or fragment injuries. (**a**) Rocket-propelled grenade lodged in the left thoracic cavity. (**b**) Commonly seen pattern of multiple small fragments throughout the trunk

For patients with evidence of cardiac tamponade, perform FAST exam to detect pericardial fluid and move immediately to the operating room. If you have tamponade physiology or by ultrasound examination with penetrating chest trauma, you do not need to waste time with a pericardial window. Proceed immediately to median sternotomy and fix the hole in the heart.

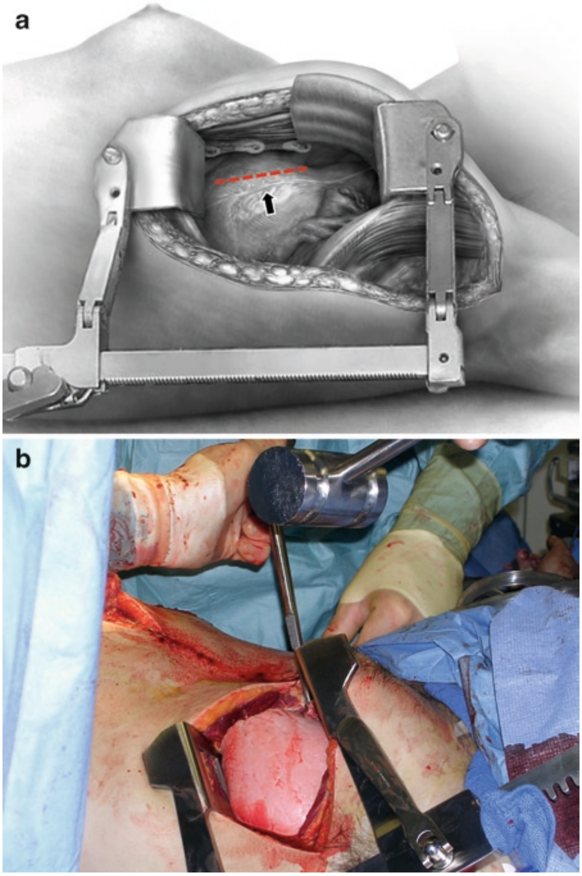

Fig. 15.2 Exposure from a left anterolateral thoracotomy. (**a**) The pericardium should always be opened anteromedially (*dotted line*) to avoid injury to the phrenic nerve (*arrow*). (Reprinted with permission from Campell, Operative Techniques in General Surgery 2008;10:778–786). (**b**) Extension of an anterolateral thoracotomy across the sternum using a Lebsche knife

For patients with penetrating thoraco-abdominal injury where the abdominal injury predominates, perform trans-diaphragmatic pericardial window during laparotomy if indicated. Standard indications include (1) the presence of pericardial fluid on FAST exam, (2) missiles or fragments in the vicinity of the heart on X-ray or CT scan, (3) suspicious trajectory (i.e. trans-mediastinal), and (4) sudden hemodynamic deterioration without another obvious cause.

In patients who are hemodynamically stable on presentation, perform the usual diagnostic evaluation (history, physical examination, plain radiographs as dictated by sites of injury, FAST exam, and CT as indicated). Do not delay or prolong your evaluation since patients with PCI can deteriorate rapidly. Patients with suspicious penetrating wounds and pericardial fluid on FAST and/or CT should be evaluated immediately in the operating room with subxiphoid pericardial window followed by median sternotomy if hemopericardium is present.

Important Techniques in the Diagnosis and Management of PCI

These techniques should be employed in the operating room under general anesthesia with the patient prepared and draped from above the sternal notch to below the inguinal creases bilaterally. The operative field created gives you access for pericardial window, median sternotomy, laparotomy, and exposure of the femoral vessels as needed.

Pericardial Window

You should use subxiphoid pericardial window to confirm hemopericardium in patients who have penetrating chest, neck, and/or upper abdominal injuries and pericardial fluid on FAST or CT. Make a midline incision over the xiphoid process extending 2–3 cm inferior to the tip of the xiphoid. Use cautery to divide the subcutaneous fat in the midline, exposing the linea alba. Free the tip of the xiphoid and grasp it with a Kocher clamp. Use cautery to free the xiphoid from the soft tissue attachments and excise the xiphoid using a curved Mayo scissor. Palpate the underlying pericardium and bluntly dissect tissue off the pericardium posteriorly. Grasp the pericardium with an Allis clamp and incise it with a 15-blade or bovie. Extend the pericardial incision posteriorly with Metzenbaum scissors. The character of the fluid expressed should be evident. Evacuate the pericardial fluid with suction for further evaluation and to evacuate clot. If hemopericardium is encountered, median sternotomy is indicated. If there is only a small volume of serous fluid, place a small channeled drain (10 mm Blake) in the pericardial space through a separate stab incision through the rectus abdominus fascia and skin. Close the fascial defect and skin with suture of your choice. Secure the drain to the skin with a nylon or silk suture 2-0 or larger and place the drain to bulb suction.

When performing a pericardial window during resuscitative thoracotomy, incise the pericardium longitudinally 2–3 cm anterior and parallel to the phrenic nerve (Fig. 15.2). Extend the incision inferiorly and T it off as needed for more exposure to identify PCI and to perform defibrillation or internal compressions. If there is hemopericardium or an obvious cardiac injury, then the pericardium should be opened widely to deliver the entire heart from the pericardial sac.

To perform trans-diaphragmatic pericardial window, divide the triangular ligament and retract the left lobe of the liver to the right. Retract the stomach and esophagus inferiorly, and identify the midportion of the diaphragm "by projecting an imaginary line from the xiphoid to the esophagus posteriorly." Grasp the diaphragm with Allis clamps and incise the diaphragm vertically 3–4 cm. You will then view the pericardium, and you should incise it similarly. If there is no hemopericardium, close the diaphragm incision with interrupted suture (2-0 Prolene). If you encounter hemopericardium, median sternotomy is indicated.

Median Sternotomy

Start with a midline incision from the sternal notch to the tip of the xiphoid process (or connect with the incision you made for the subxiphoid pericardial window). Divide the subcutaneous fat with cautery to the level of the pectoralis major fascia. Palpate the sternal notch and use cautery to divide the sternoclavicular ligament in the midline until you can hook your index finger around the sternal notch, palpating the posterior manubrium. Next identify by palpation the second intercostal space bilaterally and mark the midline of the sternum with cautery at that point. Use cautery to divide the tissue in the midline from the sternal notch to the second ICS. Divide the fascia over the midline xiphoid until you can hook your index finger to palpate the posterior sternum inferiorly. Use cautery to divide the tissue in the midline from the second ICS to the xiphoid. Use the battery-powered sternotomy saw or Lebsche knife to divide the sternum in the midline following the cautery line you created (Fig. 15.3). Stop bleeding from the anterior and posterior tables of the sternum with cautery. Cautery will not stop marrow bleeding, so use a topical hemostatic agent. Floseal Hemostatic Matrix (Baxter Healthcare Corporation, Deerfield, Illinois) works well. Bone wax may be available, but some evidence suggests that it increases the risk of mediastinitis and sternal non-union.

Before closing the sternotomy, place at least one mediastinal closed suction drain. Bring it out through the upper abdominal fascia without violating the peritoneum. A channeled 19 Fr Jackson-Pratt drain connected to a Pleurevac or bulb suction works well, but 24 Fr or larger chest tubes will also work. If either pleural

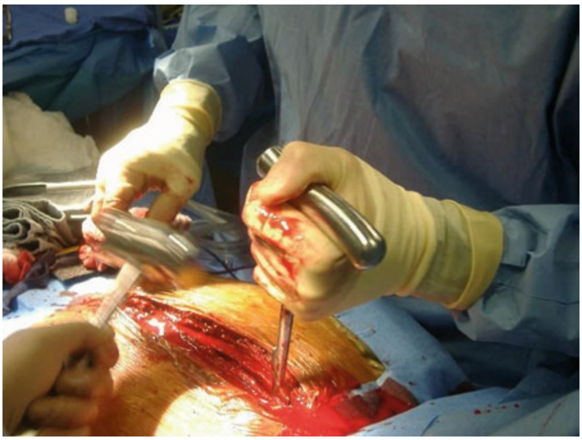

Fig. 15.3 Combat median sternotomy being performed using a Lebsche knife to divide the sternum

space is violated (and the right pleura is often inadvertently opened during the sternotomy), then place a chest tube 24 Fr or larger into the pleural space. These chest tubes may be brought out near the midline next to the mediastinal drain. Close the sternotomy with interrupted stainless steel wire – for adults use #5 or larger. I prefer #7. Three wires *through* the manubrium and four *around* the body of the sternum (through interspaces) should suffice. Take care not to plunge through the posterior table into the right ventricle. Having your assistant lift up on the sternum with a rake or Army-Navy retractor helps to prevent this complication. Close the fascia, deep dermis and subcuticular layers with running absorbable suture (2-0 Vicryl for fascia, 3-0 Vicryl for deep dermis and 4-0 Monocryl for subcuticular) unless wound contamination or other considerations such as substantial soft tissue loss dictates otherwise.

Pericardial Well

Creating a pericardial well increases exposure for you to identify and repair PCI. After positioning the sternotomy retractor and opening it five to seven clicks, use cautery to divide the mediastinal fat overlying the pericardium. Use cautery or a 15 blade to incise the pericardium. When incising the pericardium it is best to grasp the pericardium with Debakey forceps or Allis clamps, lifting the pericardium away from the right ventricle. This may not be possible with a tense pericardium. Once the pericardiotomy is large enough, insert a plastic sucker tip or a finger to protect the myocardium as you use cautery to extend the pericardial incision inferiorly toward the diaphragm. Use cautery to create a T-incision at this level. To the right you will palpate a dimple in the pericardium, and your T-incision should stop there. To the left, T the incision toward the ventricular apex as far as you can visualize, again using your finger to protect the underlying myocardium. Superiorly you will need to divide thymic fat to expose the underlying pericardium. Use clips or ligatures when you divide the veins in the thymic fat because they drain directly into the innominate vein and can become a source of blood loss. There is usually no need to skeletonize the innominate vein, but do identify and avoid it. Extend the pericardial incision superiorly over the midline of the ascending aorta and stop where the pericardium attaches to the aorta. Use 0 silk sutures to suspend the pericardium at the level of the ascending aorta, the right atrial appendage and the inferior T-incision, bilaterally (six total, three each side). Secure the sutures to the skin or around the sternotomy retractor (Fig. 15.4). When you spread the retractor further (to 10–12 clicks) the pericardial sutures will open and lift the pericardium providing necessary exposure.

There is no need to close the pericardium. If the patient's wounds are multiple and extensive and the patient has received large volumes of fluid resuscitation and blood transfusions, then it is best not to close the pericardium. If there is no PCI and/or limited injury and resuscitation, then pericardial closure can be performed over a closed suction drain using 3 or 4 interrupted 0 silk sutures. The closure need not be water tight.

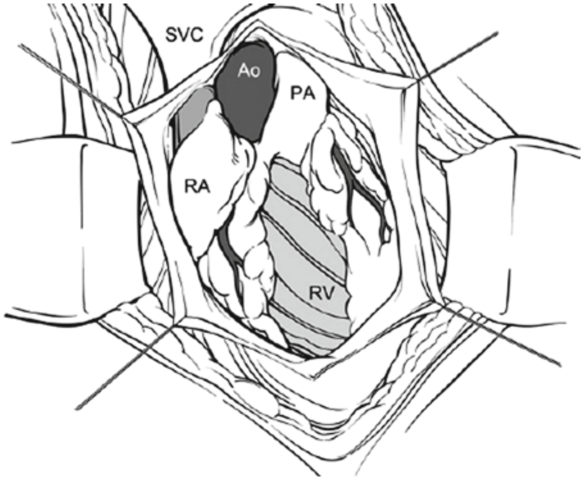

Fig. 15.4 The pericardial well technique. Place four to six pericardial sutures and secure them to the retractor. As the retractor is opened the sutures will tent up the pericardium providing excellent retraction and exposure. (Reprinted with permission from Meredith et al., Surgical Clinics of North America 2007;87:95–118)

Identifying Penetrating Cardiac Injury

You must inspect all intra-pericardial contents for evidence of injury. Bleeding and hematoma are clear signs of injury. Active bleeding may be difficult to identify if the injury is located posteriorly (Fig. 15.5). Ensure you have tested and ready internal defibrillator paddles on the field and notify the anesthesia provider before manipulating the heart. Volume resuscitation and Trendelenberg position can help to minimize the decrease in blood pressure that cardiac manipulation produces.

The right atrium, right ventricle, ascending aorta, main pulmonary artery (PA), and vena cavae are readily inspected with little or no manipulation (Fig. 15.6). The left atrial appendage can be visualized just to the left and posterior to the main PA. To inspect the more posterior right atrium and right pulmonary veins have the anesthesia provider hold ventilations briefly as you push the right pericardium toward the right pleural space with your suction and your assistant gently retracts the right atrium to the left. To inspect the anterolateral, inferior and posterior left ventricle, as well as the left pulmonary veins and the left atrium, gently lift the cardiac apex out of the pericardial space using a dry laparotomy pad for traction. Inspect these areas briefly if hypotension and dysrhythmias occur. You can place one or multiple folded, warm, moist laparotomy pads posterior to the left ventricle to facilitate exposure of the left anterior descending coronary artery and the anterior left ventricle and apex. This is usually tolerated well hemodynamically.

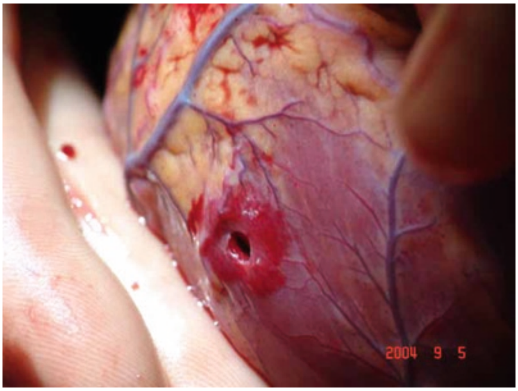

Fig. 15.5 Close inspection of the entire posterior surface is performed to identify these small fragment injuries that may have minimal initial bleeding and be easily missed

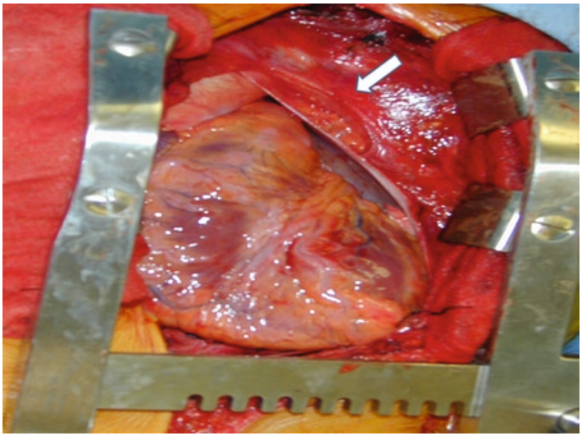

Fig. 15.6 Anterior exposure of the heart through a median sternotomy. The right atrium, right ventricle, ascending aorta, main pulmonary artery (PA), and vena cavae are readily inspected with little or no manipulation

Repairing Penetrating Cardiac Injury

Unless there is obvious massive hemorrhage originating elsewhere in the pericardium, injuries should be repaired as they are encountered. Bleeding should be controlled temporarily, if possible, using digital pressure, while repair is planned. Some injuries are easily accessed, but others require you to lift the cardiac apex to expose the injury. In these instances it is easiest for you to suture in concert with the cardiac rhythm with your dominant hand while holding position with your non-dominant hand. Attempting to suture with your assistant retracting the heart is usually more

Fig. 15.7 Repair of cardiac laceration with interrupted Prolene suture reinforced with pledgets

difficult. When the suture is complete, maintain exposure with your non-dominant hand and have your assistant tie the suture.

Atrial injuries may be located in a position, such as the right or left atrial appendage or right atrial free wall, where a partial occluding vascular clamp may be applied to maintain hemostasis while repair is accomplished. Do not occlude the right coronary artery with the clamp, and do not retract too vigorously on the clamp because the thin-walled atrial tissue might tear, making repair more challenging. Repair of atrial lacerations may be completed with running, double-armed 4-0 Prolene suture on an SH needle. Interrupted U stitches of pledgeted 4-0 Prolene may also be used. There is no contraindication to the use of pledgets when repairing any great vessel or external cardiac injury, and all ventricular lacerations should be repaired using pledgets. Teflon felt and autologous pericardium work well.

You should repair ventricular lacerations with interrupted U stitches of pledgeted 3-0 Prolene on an SH needle (Fig. 15.7). Individual pledgets may be used, but strips of Teflon felt or autologous pericardium 1 cm in width running the length of the repair are also useful. The needle should enter one side of the laceration and exit the other side in one pass. Each needle is passed across the laceration then placed through the free pledget. The suture is tied taking care not to tear the myocardium

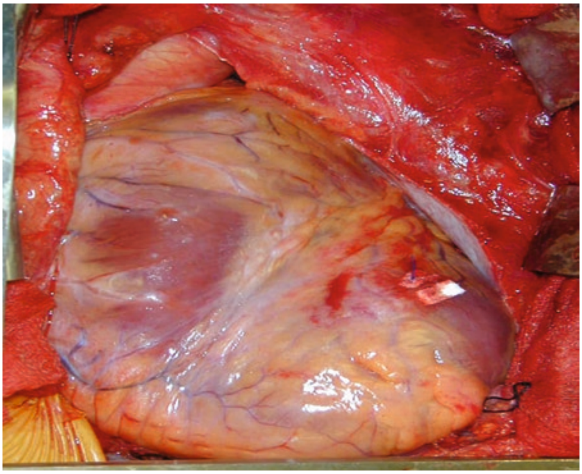

Fig. 15.8 Repair of a right ventricular laceration with a pledgeted Prolene suture

(Fig. 15.8). The anterior right ventricle is particularly thin and prone to tearing as you tie the suture, extending the laceration sometimes beyond repair. Take care to not inadvertently ligate a coronary artery in the laceration repair.

Some atrial and ventricular injuries are not bleeding when you identify them. Small epicardial and intramural hematomas need not be repaired. I would always recommend leaving a pericardial drain in this scenario to provide rapid diagnosis of subsequent hemorrhage and avoid tamponade. If you have identified a full-thickness laceration or cannot rule out a full-thickness injury then you must repair the PCI as described above.

If bleeding is so massive that you cannot visualize the wound edges to repair the injury, you may use inflow occlusion to temporarily suspend venous return to the heart, allowing visualization of the wound edges and expeditious placement of U stitches of pledgeted 3-0 or 4-0 Prolene suture on an SH needle (Fig. 15.9). First obtain circumferential control of the superior vena cava (SVC) by dividing the adventitial tissue to the left and right of the SVC and anterior to the right main pulmonary artery. Use a renal pedicle clamp to secure a moistened umbilical tape around the SVC and pass the tape through a Rummel tourniquet made from a 12 or 16 Fr red rubber catheter. Also obtain circumferential control of the inferior vena cava (IVC), bluntly dissecting by spreading with Metzenbaum scissors perpendicular to the IVC at its junction with the right atrium. You may feel more comfortable encircling the IVC with your left thumb and index finger, bluntly dissecting the tissue posterior to the IVC. Pass a renal pedicle clamp posterior to the IVC within the pericardium to secure a moistened umbilical tape around the IVC and pass the tape through a Rummel tourniquet. Have suture loaded and ready to use when you occlude the SVC and IVC by cinching the umbilical tapes in the Rummel tourniquets. The patient's systemic blood pressure will decrease to nothing, and ventricular fibrillation may result. You may repeat the process several times, allowing recovery

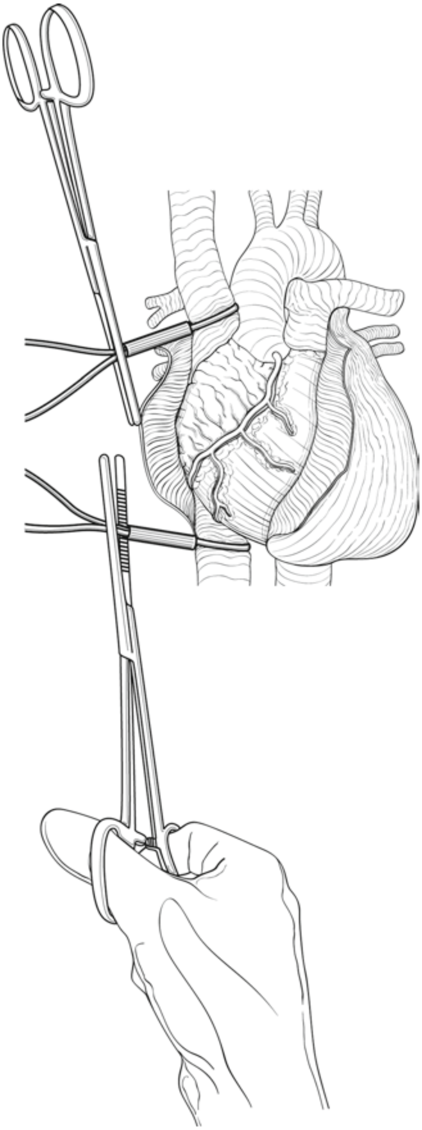

Fig. 15.9 Technique for establishing complete inflow occlusion to the heart

between iterations, until the PCI repair is completed or visualization no longer requires inflow occlusion.

Lacerations of major coronary arteries should be repaired if possible, but ligation may be the only option when the necessary equipment for coronary artery bypass is not available. Smaller coronary artery branches and coronary veins that are bleeding should be ligated with 4-0 or 5-0 Prolene suture on an RB-1 or SH needle.

If a PCI is located adjacent to an intact coronary artery, repair the injury with pledgeted U stitches of 3-0 or 4-0 Prolene suture on an SH needle. The needles should pass *under* the coronary artery, and the pledgets should be on either side of the vessel so flow in the vessel is not compromised.

Intra-cardiac Injury

As a trauma surgeon managing penetrating cardiac wounds, you must be as cognizant of the possible "hidden" injuries as you are of the dramatic and obvious myocardial injury. These will mainly consist of injuries to the valves resulting in incompetency or injuries to the septum resulting in a primarily unidirectional (left to right) shunt. Thankfully, the majority of these injuries that survive to the operating room will be well tolerated and compensated, and not require any emergent intervention. However, major valvular incompetency (from the injury or from the repair) can result in significant hemodynamic changes and atrial or ventricular dilation that can be life-threatening. Have a high index of suspicion in all patients with cardiac wounds and use whatever means you have available to make an early diagnosis. With the widespread use of ultrasound in even the far forward setting, you should have the ability to do a basic trans-thoracic or even a trans-esophageal echocardiogram (Fig. 15.10). In combination with your physical exam and hemodynamic assessment, you should be able to identify the presence of an intra-cardiac injury and begin medical therapy (i.e. afterload reduction, inotropes, etc.). In the combat setting you will not have access to the

Fig. 15.10 An intraoperative trans-esophageal echocardiogram being performed during repair of a cardiac wound in a Combat Support Hospital, Tikrit, Iraq

equipment or support that you need to do complex open heart surgery, so evacuate or transfer the patient as soon as is practical.

Summary

Surgeons of all backgrounds who are deployed to a combat setting should mentally prepare for the challenge of penetrating cardiac injuries. They are rare enough that few experts exist, but common enough in the combat environment that chances are high you will encounter at least one on a 6 month deployment to a busy combat support hospital. Your review should include simple matters, like performing a pericardial window and opening and closing the sternum, to the higher complexity situations as outlined above. Because of their rarity, the management of penetrating cardiac injuries is one area where prior reading and mental preparation will serve you (and your patient) very well. Be calm, be decisive, think big but act precisely, and you will lead your team to success.

Chapter 16
Thoracic Vascular Injuries: Operative Management in "Enemy" Territory

Benjamin W. Starnes

Deployment Experience:

Benjamin W. Starnes Operation Noble Anvil, Task Force Hawk, War in Kosovo, 1999
Vascular Surgeon, Operation Iraqi Freedom, Kirkuk, Iraq, 2003
Vascular Surgeon, Operation Iraqi Freedom, Kirkuk, Iraq, 2004

BLUF Box (Bottom Line Up Front)

1. All penetrating thoracic wounds should be assumed to have hit the heart or a big blood vessel until proven otherwise.
2. If you have hard signs of a vascular injury, then the place you need to be is the operating room, not the CT scanner.
3. The battle is won by choosing the correct incision and knowing where to get proximal control. The rest is easy.
4. Don't go diving into hematomas until you are prepared and your anesthesia team is ready for massive blood loss.
5. Ligate and divide the innominate vein to access the proximal great vessels.
6. Know what you can safely ligate. Almost all veins and the subclavian arteries can be safely ligated with little sequelae – exceptions in the chest are the IVC and SVC.
7. Open vascular surgery techniques are still required in combat and disaster surgery.
8. Ensure you have adequate suture and vascular grafts BEFORE you need them.
9. If you have endovascular capability, use it! It can provide easy vascular control for your operative repair or help you avoid a difficult and bloody operation altogether.

Whenever you encounter massive bleeding, the first thing to remember is that it is not your blood

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Introduction

One of the features that distinguish a great surgeon from a good surgeon is the ability to remain calm under pressure, strongly direct a team of providers and stay focused on the mission at hand. Thoracic vascular injuries can make for good theater and subsequent tall tales when there is a successful outcome, but nowhere is it more critical to be in the "great surgeon" mindset than with the management of these unforgiving injuries. "Control" is the operative term. Despite the divergence of Vascular and General Surgery in the civilian sector, every combat Trauma Surgeon needs to have the basic vascular surgery knowledge and skillset to manage these injuries. Consultation with a Vascular Surgeon or transfer may not be an option.

Rule number one. When preparing to open a chest, whether in the emergency department or operating room, check your own pulse first. Slow your respirations and heart rate and get to work. Your movements must be methodical and controlled. There can be no gross or uncontrolled maneuvers and you must keep other excitable assistants or "ham-handed" surgeons out of the way. Speak directly and with confidence to your team members. You will get one shot at saving this life. Move the gawkers out of the way and finish the operation. You are not a hero just because you can open a chest. It's what you do AFTER you open the chest that counts.

Wounding Patterns and Physiology on the Modern Battlefield

Military surgeons are routinely trained in non-military environments and as such, may be unprepared for life on the battlefield. Howard Champion in 2003 described six unique considerations with regard to acute resuscitation in a combat setting: (1) the high energy and lethality of wounding agents; (2) multiple causes of wounding; (3) preponderance of penetrating injury; (4) persistence of threat in tactical settings; (5) austere, resource-constrained environment; and (6) delayed access to definitive care.

The majority (~75%) of survivable chest wounds on the battlefield can be managed with simple tube thoracostomy. Greater than 90% of vascular injuries can be diagnosed based on the history and physical exam findings alone. Hard signs suggesting a vascular injury include: pulsatile bleeding, expanding hematoma, palpable thrill, audible bruit, and evidence of ischemia as indicated by pulselessness, pain, pallor, paresthesia, and paralysis in an affected upper or lower extremity, or stroke when dealing with injury to the great vessels. Soft signs of vascular injury include a history of moderate hemorrhage at the scene of injury, injury in proximity to a named vessel, decreased but present pulse, non-expanding hematoma, and associated peripheral neurologic deficit. Hard signs do not require a lot of workup – in general they belong in the operating room ASAP!

Classic wounding patterns that should cause one to suspect major thoracic vascular trauma include the presence of hemorrhagic shock, jugular venous distension suggesting SVC syndrome or cardiac tamponade, an expanding hematoma at the base of the neck or a discrepancy in pulse exam between each upper extremity or between the upper and lower extremities. The trajectory of the penetrating wound should also lend clues to the nature of the injury. Bullets can take somewhat unpredictable courses or ricochet off of bony structures, but they can't defy the laws of physics. For single projectile wounds knowing the entrance and exit site greatly assists you in focusing your evaluation on the area at risk. For stable patients with no obvious indication for surgery, CT scan with IV contrast is an excellent tool for evaluating critical structures and also for reconstructing the trajectory of the missile or the location of multiple fragments. It is particularly useful for proven or suspected trans-mediastinal wounds.

Pre-operative Management

A classic primary survey should commence immediately in the Emergency Department (ED) simultaneously with attempts at resuscitation. In the presence of suspected massive thoracic vascular injury, venous access should be established if possible in the lower extremities or at least in the upper extremity that seems least likely to be involved with the injury.

If the casualty needs to be transferred to a higher echelon of care; for example from a Forward Surgical Team to a Combat Support Hospital, chest tubes should be placed prior to rotary wing transfer. These patients are essentially inaccessible during transport in a modern evacuation helicopter and placement of a chest tube en route can be extremely difficult. If there is concern for exsanguination from chest tube placement, the thoracotomy should have already been initiated and your decision to transfer was incorrect. The patient described won't survive transport and needs your expertise now.

If the patient rapidly decompensates in the ED with suspected thoracic vascular injury or if you witness cardio-vascular collapse, a resuscitative antero-lateral thoracotomy through the fourth or fifth interspace is required. Upon entering the chest, the location of the injury should be identified. Inspect the heart. If the pericardium is tense, you need to incise the pericardium sharply and longitudinally anterior to the phrenic nerve. Deliver the heart out of the pericardium and begin compressions against the sternum with the palm of your hand if needed. Be gentle!

If there is a lot of blood in the left chest and the patient's heart appears empty, incise the parietal pleura over the aorta to be able to get a clamp fully across the aorta to the spine, and clamp with an atraumatic clamp. Remember that you are now on a clock so mark the time in your head. You have just less than 30 min to release that clamp and the more time that passes by, the more risk this patient has of dying from uncontrolled coagulopathy, liver failure, or reperfusion injury. If you get the patient back – continue your resuscitation but get the patient to a place where you can conduct a formal operation.

Patient Preparation

We have found the orientation of the operating room in a Forward Surgical Team to be best with OR beds oriented in a head to head fashion. This allows a central station for anesthesia providers who can then care for and administer blood products to each patient simultaneously. This decreases the movement around the OR beds by multiple personnel thus potentially lowering the risk of contamination of sterile fields (Fig. 16.1).

Patients with suspected thoracic vascular injuries should be prepared for operation with standard surgical approaches in mind and with additional preparations allowing for access of more proximal vascular control. In addition, preparation should be made for recovery of an adequate vein for a reconstructive conduit from an uninvolved extremity. Hence, patients with suspected thoracic vascular injuries should have the entire chest and neck prepped into the field to allow for rapid performance of median sternotomy or thoracotomy, as well as preparation of one or both of the lower extremities to allow for recovery of the greater saphenous vein for conduit. In the chest, the first goal is to stop the bleeding and then perform a definitive repair. If suture won't fix the problem, a large prosthetic graft or bovine pericardial patch will. It is rare to use saphenous vein for reconstruction in the chest with the exception of

Fig. 16.1 Two-bed set up in a Forward Surgical Team operating room. Note that the beds are arranged head to head, which minimizes crowding with two teams working at once, and allows a single anesthesia provider access to the head and face of both patients

elective aorto-coronary bypass. We prefer to stock 18×9 mm collagen-coated knitted and bifurcated Dacron grafts. The tubes are long enough to repair any aortic injury and the limbs come in handy and are a perfect size for any great vessel reconstruction that is required. When you arrive at your facility, immediately inspect your current stock and supply level of vascular grafts. The time to discover what you have available (if anything) is not in the middle of one of these cases.

What Incision Do I Make?

This is one of those classic oral board type questions that actually has immense importance in these scenarios. The choice of incision for thoracic vascular trauma has been covered elsewhere in this book but will be briefly covered here as well. Simply put, in an unstable patient with suspicion for an injury to the heart or great vessels, a left anterior thoracotomy affords the most rapid approach at gaining access to the left heart, left subclavian and descending thoracic aorta. This incision can be easily and quickly extended into a clamshell to gain access to the right heart and SVC, IVC, and azygous vein. Remember to ligate the right and left internal mammary vascular pedicles when coming across the sternum. If time permits and the injury pattern is consistent, a median sternotomy affords full access to the heart, ascending aorta and great vessels (see Table 16.1).

Principles of Repair for Specific Injuries

In general, incisions of election should be made as a preference over incisions of opportunity. This is not always possible as the wound may provide adequate exposure for definitive control of the vascular injury. Proximal control is a basic tenant of vascular surgery. For those surgeons not accustomed to conducting a vascular surgical procedure, remote proximal control offers the best opportunity for success in the

Table 16.1 Ideal incisions for various thoracic vascular injuries

Injured vascular structure	Exposure
Unknown	Left anterolateral thoracotomy +/− clamshell
Ascending aorta	Median sternotomy
Transverse aortic arch	Median sternotomy
Innominate artery	Median sternotomy
Right subclavian artery	Median sternotomy or right supraclavicular if distal
Proximal left common carotid artery	Median sternotomy
Left subclavian artery	Left anterolateral thoracotomy or left supraclavicular if distal
Descending thoracic aorta	Left posterolateral thoracotomy
Superior vena cava	Median sternotomy
Suprahepatic inferior vena cava	Right thoracoabdominal with splitting of diaphragm

combat casualty. Don't hesitate to extend incisions across costal margins or widen the exposure to get control. Similarly, don't ever let something like the clavicle stand between you and adequate exposure of the subclavian vessels or carotid/vertebral take-off points. Resection of a portion of the clavicle can be done rapidly and provides excellent exposure of the subclavian artery and vein to obtain control and perform repair or bypass.

Upon exposure, the first goal is to get control of the bleeding. This often requires just simple digital control. Unfortunately, on the battlefield, holes in arteries can be bigger than one's digit so this is not always possible. If the injury is easily controlled with the tip of an index finger this is where a calm approach will save the day. First, *slow down*. If you now have control of the injury, communicate with your anesthesia colleagues and allow them to catch up. If the patient is hypertensive, ask them to lower his blood pressure to below 90 systolic. *Wait for your pitch*. Once the conditions are right, you can start to repair this large vessel by sewing under the tip of you finger with a 3-0 prolene and slowing advancing your finger backward over the injury. Take large bites and use pledgets if needed on the first stitch. Before you know it, the injury will be repaired. Remember that shunting or even ligation (with or without later reconstruction) is an option for most thoracic vessels.

Ascending aorta. These injuries are usually fatal at the scene but if small, can be survivable. The previous paragraph describes such an approach to this injury. Remember that the ratio of elastin to collagen in the proximal aorta is much higher. This means that the aorta in this region is more expansile but can tear very easily. Remember to use pledgets and take large bites. A DeBakey Bahnson clamp can be useful to side-bite the ascending aorta in order to get control while maintaining forward flow.

Proximal great vessels. When approaching these vessels through a median sternotomy, it is extremely important to get proximal control first. This means NOT diving into a hematoma in the superior mediastinum but opening the pericardium and marching up the ascending aorta. It is important to divide the left innominate vein between ligatures to expose this region (Fig. 16.2). As stated previously, it is o.k. to clamp the base of the innominate for repair of an innominate artery injury. Likewise, it is o.k. to clamp the base of a left common carotid injury. It is deadly to clamp both simultaneously. For elective situations, clamping both of these vessels would require the use of deep, hypothermic circulatory arrest and this won't be available to you on the frontline. You will have to do your best to individually repair these injuries. An alternative is to stage the repair by first sewing a 9-mm Dacron conduit to the ascending aorta and bypassing individually to the innominate artery, then going after the left common carotid injury with either suture repair or bypass depending on the circumstances.

Proximal left subclavian injuries are among the most challenging to handle due to their location. The ideal exposure for these injuries is a left posterolateral thoracotomy which is not a standard exploratory incision for trauma; you will usually be working from a sternotomy or anterior thoracotomy. Don't waste time and blood loss struggling to expose and repair the injury from these incision. Just reach your hand (or a sponge stick) up to the apex and compress the area of hemorrhage – this will stop the bleeding. You can now decide on how best to approach the injury. Adding an infraclavicular

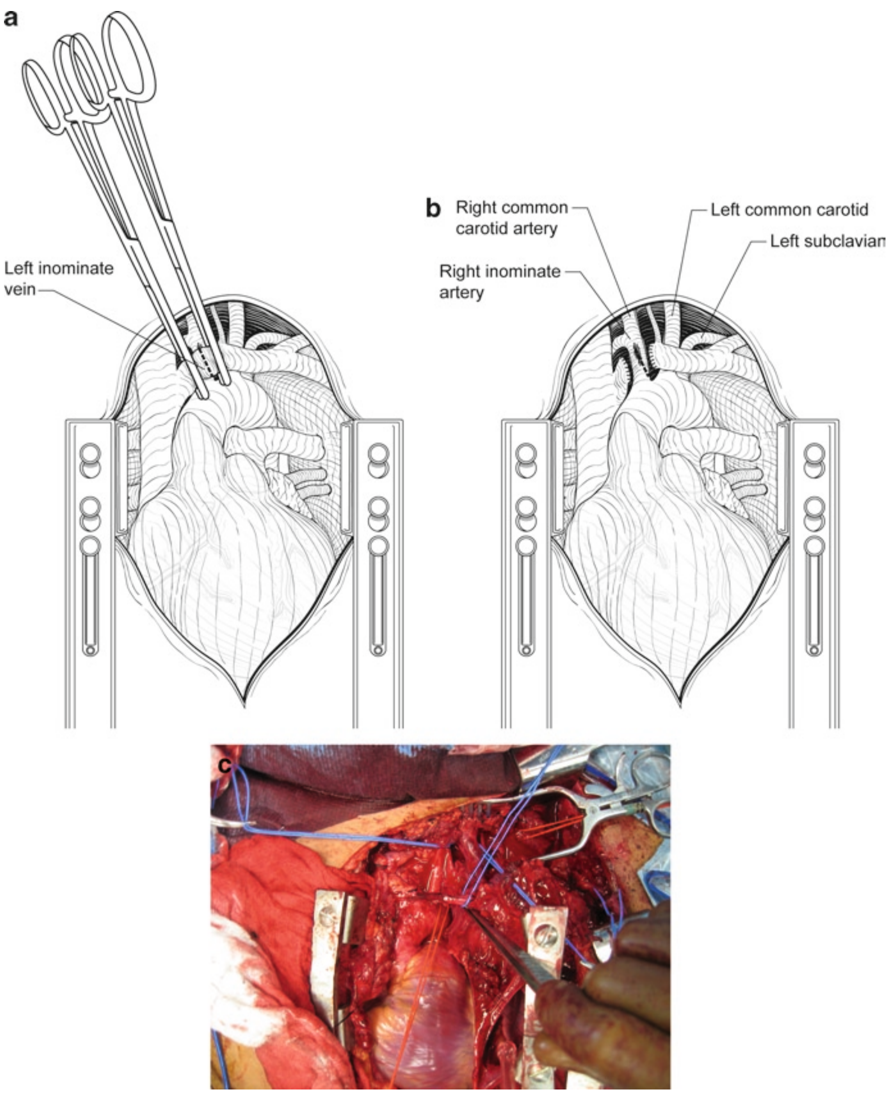

Fig. 16.2 (**a**) The left innominate vein overlying the proximal great vessels. (**b**) Great vessels exposed by ligation of the left innominate vein. The extension of the superiorly to the right neck can also improve exposure of the proximal innominate, right common carotid, and right subclavian vessels. (**c**) Intraoperative photo shows exposure of heart and great vessels, with forceps pointing to left innominate vein prior to division

incision to your median sternotomy with dislocation of the sterno-clavicular joint will provide adequate exposure. If you are in anterior thoracotomy position, you can hold pressure while repositioning the patient to lateral decubitus. If the patient is doing poorly or you have other injuries to deal with, ligate the artery; this will usually be well tolerated and if needed can be repaired or bypassed later.

Descending thoracic aorta. These are the most fun to repair and usually require only a suture repair or patch angioplasty for fragment wounds. For larger penetrating wounds, blast wounds, or blunt aortic tears you will usually need to perform a formal interposition graft (18 mm Dacron) as shown in Fig. 16.3. Remember that you have limited time to clamp this vessel (<30 min of hepatic and mesenteric ischemia), and if your clamp time exceeds this, you should consider removing the clamp intermittently (while controlling the injury with a finger tip) in order to give the liver a "drink" of the good kind, blood. You will need to accept the moderate blood loss that will be associated with this maneuver. A left posterolateral thoracotomy is ideal, but you may often need to do it through an emergent anterolateral thoracotomy. Good exposure and retraction of the heart and lung anteromedially is critical. Although the injuring mechanisms in combat are most commonly from projectiles, you may see blunt aortic injuries from ground or helicopter vehicular crashes. These are no different than their civilian counterparts, with the exception that you will not have the immediate option of cardiopulmonary bypass. Remember that these are rarely emergent, and can initially be managed with strict heart rate

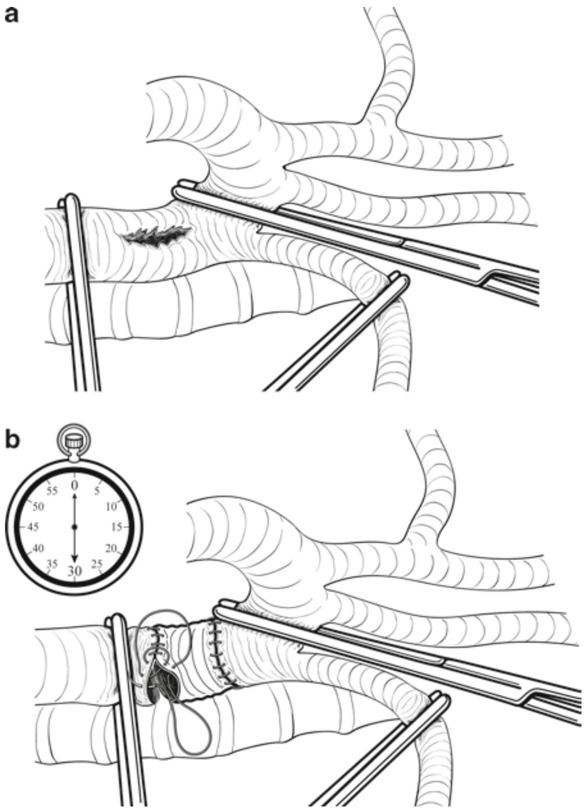

Fig. 16.3 Exposure and repair of a descending thoracic aortic injury with a prosthetic interposition graft

and blood pressure control. Approach them via a left posterolateral thoracotomy with single lung ventilation. The critical point is obtaining adequate proximal control, as the injury is typically just distal to (or involving) the takeoff of the left subclavian artery (Fig. 16.3). Gain control of the left subclavian artery before you attempt control of the proximal aorta, and be prepared to clamp the aorta proximal to the subclavian takeoff if needed.

SVC/IVC. These injuries are best approached through a median sternotomy and for more extensive injuries involving the supra-hepatic inferior vena cava, extending along the right costal margin and splitting the right hemidiaphragm. Supra-hepatic IVC injuries are incredibly lethal and even in the best of experienced hands carry a very high mortality rate. Careful control should be obtained, preferably with a side-biting vascular clamp to maintain blood flow to the right atrium. An alternative method of control is by placement of an atrio-caval shunt as described in Chap. 8. This is also usually facilitated by widely opening the pericardium and safely tracing them from the intra-pericardial portion at the junction with the right atrium, and then proceeding distally. Repair involves lateral venorrhaphy or patch angioplasty with 3-0 Prolene. You should try to avoid ligating either of these two veins at all costs due to the significant impact on venous pressure/edema and the decreased venous return to the heart.

Azygous vein. Although not thought of as a major vascular structure in the chest, injury to the azygous vein can be associated with a huge blood loss. The object of the game is to isolate and ligate this vessel. This often requires placement of sponge sticks proximal and distal to the injury through a right thoracotomy followed by ligation. Use a large prolene suture and drive the needle along the spine to encircle and ligate the vein.

Pulmonary arteries. My preferred method for control of these injuries is to place a large vascular clamp (DeBakey AG Aortic Clamp) across the pulmonary hilum until the injury can be identified and repaired (see Chap. 14). In the unstable patient with a complex injury to the pulmonary hilum, you are often better off performing a rapid stapled pneumonectomy.

Use of Heparin

We have initiated systemic heparinization (50–75 U/kg IV) in *stable* patients in whom vascular control of the injury has been quickly established, estimated pre-hospital blood loss is relatively low, and ongoing bleeding sources are minimal. Unstable patients with diffuse hemorrhage from bone fragments, torn muscle and additional injuries, and patients who are already hypothermic and coagulopathic, should not get systemic anticoagulation. Alternatively, local administration of heparinized saline solution directly into the injured vessel prior to repair may aid in preventing thrombotic complications. The decision to anti-coagulate is left to the discretion of the operating surgeon, who must be in close contact with the anesthesia providers in order to fully understand the patient’s clinical status. In general, aortic injuries that can be repaired with a side-biting clamp or digital control don't require supplemental heparin due to the high flow in these vessels. If you find your repair is clotting and there is no technical defect, then you should proceed with systemic anticoagulation.

Shunts

In my opinion, shunts have a limited role in the management of thoracic vascular injuries. Temporary clamping of any of the great vessels individually is usually well tolerated due to collateral circulation. Clamping of both the innominate and left common carotid should be avoided at all costs due to the extreme risk of stroke. However, they may be extremely useful in the far-forward setting if you don't have the time, resources, and expertise to perform any type of vascular repair and maintaining forward flow is crucial.

If used appropriately, temporary intraluminal shunts allow for rapid restoration of blood flow to an ischemic limb or to the brain while other procedures to include wound debridement, external fixation of fractures or more life saving procedures such as trauma laparotomy or thoracotomy can be accomplished. Shunts may be easily and rapidly placed after proximal vascular control with either a pneumatic tourniquet or vascular clamp, and secured in place with Rummel tourniquets or simple silk ties to prevent dislodgement. After placement, patency should be confirmed with intra-operative Doppler of the shunt and distal flow. I recommend the specific use of Sundt shunts as their design minimizes risk of dislodgement when appropriately inserted. The Sundt shunt is lined with an inner coil to prevent kinking or collapse (Fig. 16.4). There is one small area within the shunt of discontinuous coils which should be used for clamping if needed. Clamping the shunt in any other location will crush the coil and occlude the shunt. In a pinch, any sterile hollow tube with adequate flow characteristics

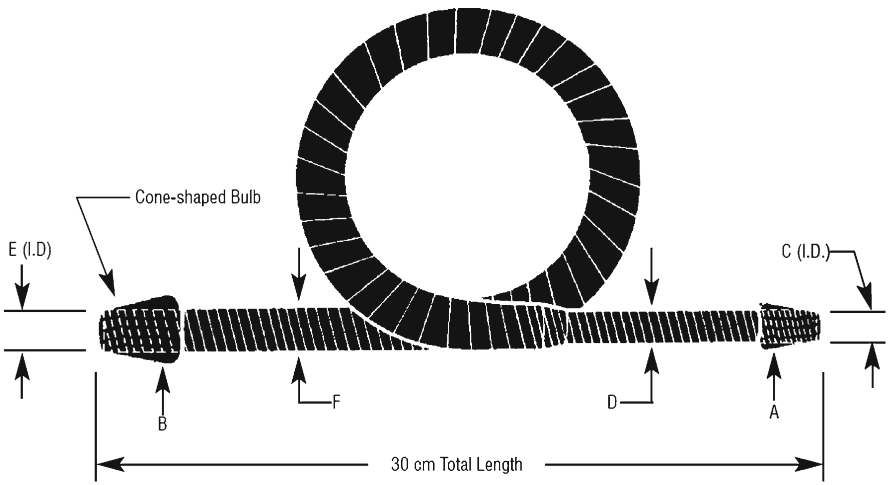

Fig. 16.4 The Sundt External Shunt (Integra Neurosciences™, Plainsboro, NJ) with inner coil reinforcement. The tapered ends make it easier to insert and secure in the vascular lumen

can be used as a shunt. For smaller vessels a nasogastric tube has frequently been used, and for larger vessels an appropriately sized chest tube may be utilized.

Surgical Technique

As with all vascular operations, there are several important elements for success. Key among these is careful handling of tissue, use of magnification loupes, adequate lighting and use of fine instruments with fine, mono-filament suture. These requirements are not always met on the battlefield and the operating surgeon can be faced with challenging circumstances beyond his/her control.

After exposure, injured vessels should be carefully debrided back to normal and healthy appearing tissue. Inflow and back bleeding should then be assessed. If there is no back bleeding, gentle thrombectomy with appropriate sized Fogarty embolectomy catheters should be performed. The use of a standard pulmonary artery catheter may be useful in this scenario if no standard catheters are available. Minimal manipulation of intima is imperative to prevent vessel thrombosis in the early post-operative setting. After adequate debridement, the vessels should be flushed with a heparinized saline solution both proximally and distally. A tension-free (but non-redundant) repair should then ensue. With combined injuries, arterial repair should precede venous repair except when venous repair requires little effort. The decision to repair venous injuries as apposed to ligation depends of the stability of the patient and demands to treat other injuries. Ligation of venous injuries is usually preferred in the chest unless dealing with the IVC or SVC.

Conduits

Key to the success of vascular repair in the combat setting is appropriate use of available conduit for reconstruction. It is widely held that the best alternative conduit for reconstruction is autologous saphenous vein. The saphenous vein is the workhorse for vascular surgeons and can be used in multiple locations but in the chest where the vascular structures are large, the utility of saphenous vein conduit diminishes. It is important to remember the concept of directional flow within veins and thus reverse or turn around the saphenous vein prior to using it as a conduit for revascularization. The saphenous vein may also be used as patch material and has been described to be re-fashioned in the form of panel or spiral grafts for re-construction of larger vessels. It is my opinion that spiral grafts and panel grafts should be avoided in the management of thoracic vascular injuries due to the excessive time required to create them. If used, the saphenous vein should always be recovered from an uninvolved lower extremity. Jugular veins are a suitable alternative for larger vessels, particularly if you are already in the neck.

Prosthetic conduits, when used to repair or replace blood vessels in the chest, should be made of Dacron and coated with collagen to aid in hemostasis. As stated before, the author uses 18 × 9 mm Dacron bifurcated grafts as the diameters of both the main body of the graft and the limbs can be used to replace anything in the chest.

Another useful patch material is either Bovine pericardium or the patients own pericardium. Don't hesitate to use prosthetic in the setting of esophageal injury with soilage. An infected graft can be dealt with later after saving the patient's life.

Closure of Incisions

A few comments should be made on closure of thoracotomy and sternotomy wounds after trauma. Remember to appropriately drain these wounds. These are large body cavities that can accumulate a lot of fluid and blood and impair ventilation and oxygenation not to mention cardiac contractility. For thoracotomy wounds, leave behind large (36 Fr) angled and straight chest tubes – two per hemithorax. For sternotomy wounds, don't hesitate to leave the chest open, especially if it has been a long operation and the patient has received a massive resuscitation. We typically use a plastic bovie holder wedged between the edges of the sternum followed by a sterile hand towel and iodine-impregnated adhesive drapes for the "damage control" sternotomy closure. All sternotomy wounds should be drained with 36 Fr straight mediastinal drains or Blake drains.

Endovascular Procedures

Although endovascular technology has arguably been the greatest advancement in vascular surgery in recent history, it has also resulted in a loss of basic vascular surgical skills among both staff and trainees. Remember that during the initial phases of any conflict, you may be operating with whatever instruments and equipments you can carry (Fig. 16.5). Chances are, you will not have access to a portable C-arm, power injector or the necessary equipment to perform endovascular procedures on the frontline. However, as the combat operations mature and consolidate your facility may become capable of performing advanced endovascular procedures. If you have access to this, consider yourself blessed. The endovascular revolution has dramatically changed the mortality for major thoracic vascular injuries. The ability to remotely place a clamp in the form of an occlusion balloon prior to resuscitation and repair is a huge advantage. Basic required equipment for endovascular surgery is listed at the bottom of Table 16.2. A few specific injuries deserve mention:

Blunt aortic injury (*BAI*). This injury is usually associated with rapid deceleration and blunt force trauma. Please remember that if the patient has hypotension or profound anemia, it is almost never associated with the BAI and one should seek out other causes for these phenomena. If BAI cuts loose into the left hemi-thorax, call the morgue, not the OR. These injuries can often be managed semi-electively with aortic stent grafting. Endovascular expertise is a requisite. The left subclavian artery can be covered with impunity to achieve adequate proximal seal. An example of pre and post-op images of BAI are pictured in Fig. 16.6.

Axillo-subclavian injuries. The management of these injuries in the past was associated with massive and lengthy operations. Today, in modern civilian trauma

Fig. 16.5 The 173rd Airborne Brigade, including the 250th Forward Surgical Team, stages on the tarmac for their initial combat jump into northern Iraq

Table 16.2 Required equipment for the management of vascular injuries in the field

Vascular surgical instruments	All × 2 or more
Gerald forceps 7 and 9 in.	Ryder needle drivers 5, 7 and 9 in.
Castro-Viejo needle drivers 7 in.	Deithrich Bulldog clamps 1.75 in. angled
Wiley Hypogastric clamps 7 in. × 6.5 cm	Satisnky-DeBakey clamps 9.75 in.
Profunda clamps 5.5 in.	Cooley pediatric vascular clamp 6.5 in.
Adson-Beckman retractor 12.5 in. hinged	Fogarty Embolectomy catheters 3 and 5 Fr
Jansen Mastoid retractor 4.5 in.	Potts-Smith scissors 7.5 × 45 degrees
DeBakey aortic clamp	DeBakey Bahnson aortic clamp
Supplies	
3-0 Prolene suture – 36 in. (90 cm) SH	6-0 Prolene suture – 30 in. (75 cm) RB-2
Umbilical tapes	Silastic vessel loops (small and large)
Rumel tourniquets	Sundt and Argyle shunts – 10, 12, 14 Fr
Teflon or Felt pledgets	19 g Butterfly needles
Three-way stopcock	30 cc Syringes
18 × 9 Bifurcated Dacron grafts	Ringed PTFE grafts – 6 and 8 mm
9 MHz Handheld Doppler	Plastic titest needle
Sternal retractor	Finochietto retractor
Lebsche knife	
Pharmacopia	
Heparin 1,000 U/ml, 10 ml vials	Papaverine 30 mg/ml, 10 ml vials
25% Mannitol 12.5 g/50 ml, 50 ml vials	Alteplase 2 mg vials
Ultravist contrast – 100 cc vial	Fibrin sealant (Flowseal)
Thrombin – 1,000 U/ml, 20 ml vial	Recombinant factor VII
Gelfoam	Heparin saline mix – 10 U/cc normal saline
Miscellaneous	
Headlight-Zipka	Magnification loupes

(continued)

Table 16.2 (continued)

Vascular surgical instruments	**All × 2 or more**
Endovascular supplies	
Access needle	Lunderquist DC wire – 300 cm (COOK)[a]
11 Fr Sheath	140 cm CODA Aortic Balloon (COOK)[a]
100 cm marking Pigtail catheter	Trilobed Snare
100 cm JB-1 5 Fr selective catheter	Viabahn[a] stent graft 7 mm and 8 mm × 5 cm
Bentson starter wire – 180 cm	Thoracic stent graft (Medtronic)[a]
Angled glidewire – 260 cm	22 mm × 11 cm Talent
Ultravist contrast	24 mm × 11 cm Talent

[a] COOK Incorporated (Bloomington, IN), Medtronic (Santa Rosa, CA), W.L. Gore (Flagstaff, AZ)

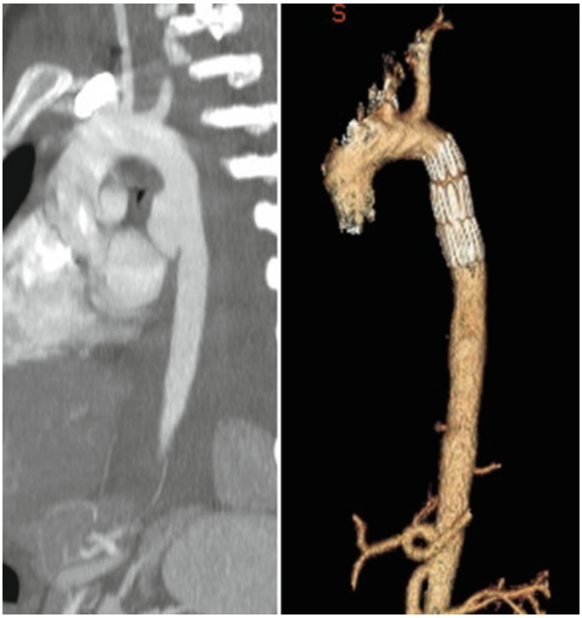

Fig. 16.6 CT scan reconstruction showing a typical blunt thoracic aortic injury with pseudoaneurysm formation (*left panel*) and the same vessel after placement of a thoracic endograft (*right panel*)

centers or even mature combat trauma facilities, these injuries can be managed in less than 30 min with an endovascular technique. Once identified, our approach is to expose the brachial artery at the antecubital crease on the side of the injury and place an 11 Fr sheath retrograde. Under fluoroscopic guidance, a wire is advanced across the injury and a catheter is advanced over the wire proximal to the injury. A contrast injection is performed and the extent of the injury identified. The injury can then easily be repaired with either a 7 or 8 mm covered self-expanding stent graft (Viabahn; W.L. Gore, Flagstaff, AZ). If the artery is completely transected, the wire will wander out into non-anatomic places. At that point, femoral access can be achieved and the ipsilateral subclavian vessel selected in the arch of the aorta. A tri-lobed snare can be advanced across the injury and the wire snared and pulled through the body creating a brachio-femoral wire. The stent-graft can now be easily advanced across this transection and repaired (Fig. 16.7).

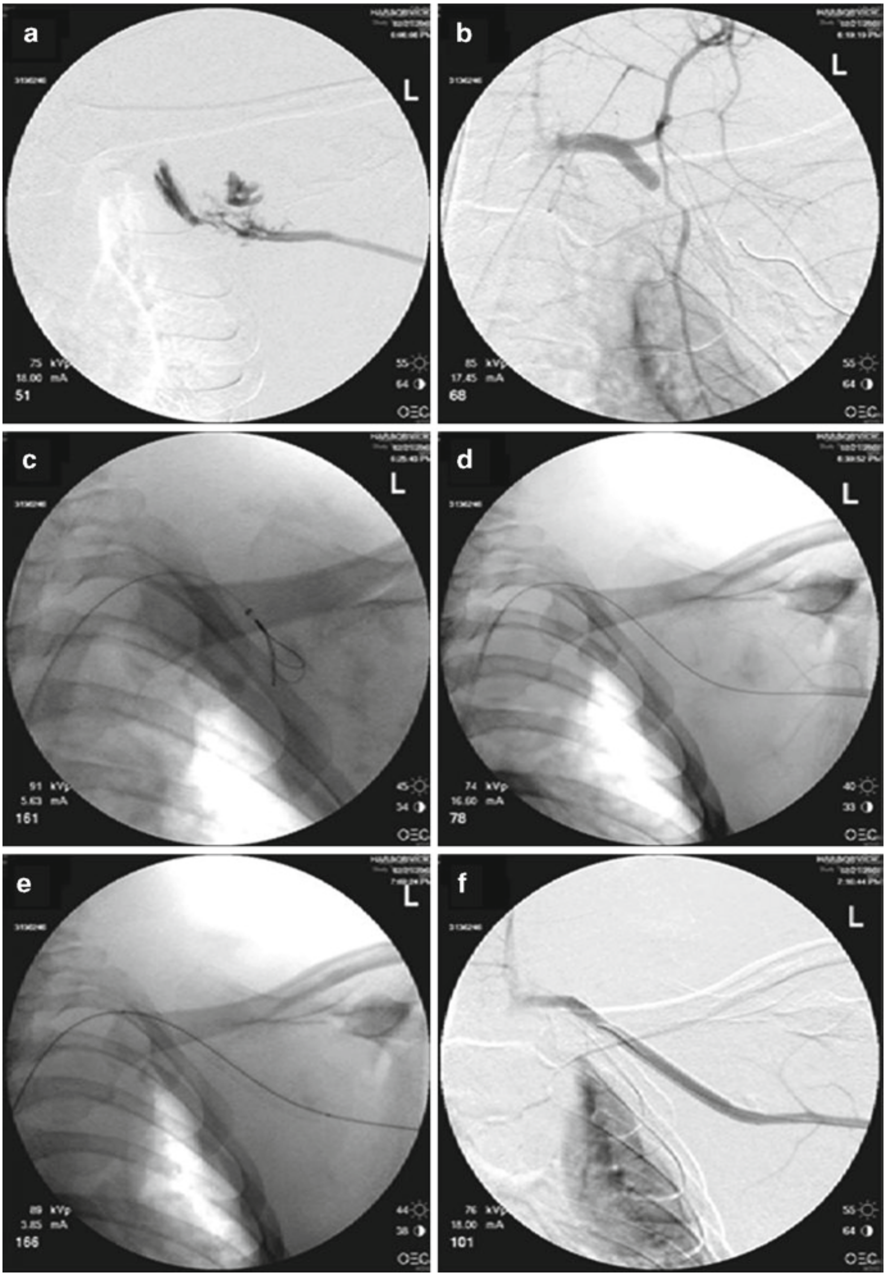

Fig. 16.7 *Panels* (**a–f**) depict repair of an Axillo-Subclavian injury using a purely endovascular technique. (**a**) Arteriogram through brachial sheath depicting extravasation and complete transection. (**b**) Arteriogram after selection of the left subclavian artery in the aortic arch. (**c**) Advancement of a tri-lobed snare across the injury. (**d**) Brachio-femoral wire spanning the injury. (**e**) Immediately post stent-graft deployment. (**f**) Completion Arteriogram

Required Equipment

Table 16.2 offers a list of suggested supplementary instruments and supplies for the performance of all basic vascular surgical procedures on the modern battlefield. All of these supplies fit easily into a single duffel bag or standard sized storage chest and are eminently transportable. This list has been compiled by the author over a period of 7 years and three combat deployments. It has proven useful to graduating residents and newly indoctrinated war surgeons. Access to portable X-ray and C-arm fluoroscopy is highly variable depending on the echelon of care and associated embedded capabilities. Most Forward Surgical Team and similar type units will not have this capability, but the majority of Combat Support Hospitals will.

In the FST, space is often limited and the availability of instruments to the surgeons can be limited. The author suggests placing individual instruments into "peel-packs" and hanging them on the operating room wall for ease of visibility, rapid acquisition and use. Your operative team may not be familiar with vascular instruments, techniques, or supplies. Conduct REALISTIC rehearsals for major vascular cases where you ask the scrub tech and circulator for all the instruments and supplies that you would normally need. Train your people well, and they will work wonders for you.

Summary

Using a calm and methodical approach, a majority of thoracic vascular injuries can be approached safely and repaired quickly. Choosing the right incision is half of the battle, and quickly obtaining vascular control without creating further injury gets you almost all of the way home. An understanding of the anatomy and different bail-out techniques outlined here is critical. You have all of the pre-requisites at your disposal to fix these injuries – just do it! Good luck.

Chapter 17
Chest Wall and Diaphragm Injury

Alec Beekley

Deployment Experience:

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Chief of Surgery, 912th Forward Surgical Team, Al Mussayib, Iraq, 2004
Staff Surgeon, 31st Combat Support Hospital, Baghdad, Iraq, 2004
Director, Deployed Combat Casualty Research Team, 28th Combat Support Hospital, Baghdad, Iraq, 2007

BLUF Box (Bottom Line Up Front)

1. The majority of chest wall injuries can be temporized with damage control techniques; complex reconstructive maneuvers should be avoided in the acute phase.
2. Chest wall injury with open pneumothorax is seen much more frequently in the combat setting than civilian settings; be prepared for it.
3. Casualties with open pneumothorax and difficulty breathing need intubation, not monkeying around with an occlusive dressing or chest tube.
4. Significant chest wall injury is associated with significant intra-thoracic injuries.
5. The best image to find diaphragmatic injuries is the one that hits your retina through an open incision.
6. Non-operative management of penetrating thoraco-abdominal combat wounds leads to worry, wasted time, complications, and usually operations at the next echelons of care.
7. Irrigate the pleural cavity through the diaphragmatic defect and place a chest tube in good position prior to closing it.
8. Early, rapid, and temporary closure of a large diaphragmatic tear can help you identify from which body cavity ongoing bleeding is really coming.
9. Patients with a diaphragmatic injuries identified at the time of laparotomy should get a chest tube on the affected side; patients with a diaphragmatic injury identified at the time of thoracotomy should get a laparotomy.

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It seems that there will always be a surgery of war. This will contribute as much to progress as war itself.

Harvey Graham, 1939

Chest Wall Injuries

Despite improvements in body armor, chest wall injuries are still common enough in combat settings that the surgeon must have more than passing familiarity with the management of them. The injuries can range from simple rib fractures, which every general surgeon has dealt with multiple times by the end of residency, to massive tissue and rib loss with eviscerated and injured lung, scapula or shoulder girdle involvement, hemorrhage, and open pneumothorax (Fig. 17.1). The vast majority of chest wall injuries can be temporized with damage control measures until other pressing injuries and physiologic needs can be addressed and stabilized. The reconstruction of chest wall defects from tissue loss can and should be delayed until the patient is evacuated to higher echelons of care, or at least until hemorrhage is well controlled, the patient resuscitated, and contamination/infection cleared up.

At the beginning of the movie "Platoon," a newly-arrived soldier is shown dying of a "sucking chest wound" after being shot in a firefight. Despite the medics' frantic application of occlusive dressings to a large left chest wound, the soldier's strangled gasps rapidly subside as he dies. This wound is almost never seen in civilian trauma settings, but will be seen fairly frequently in combat settings. It can present in stable patients and pose primarily a wound closure challenge, or it can present in unstable patients who are suffering from hemorrhage, hypoxia, and profound shock.

Fig. 17.1 Patient injured in bomb attack with a large posterior chest wall defect and open pneumothorax

Casualties with open pneumothorax have a hole in their chest wall that has less resistance to airflow than their native airways. Although textbooks talk about a hole "2/3 the diameter of the trachea" – which is somewhat cumbersome to measure at the bedside – a good rule of thumb is that if you can see directly into the chest through the hole, it is usually big enough to cause open pneumothorax.

The deployed surgeon should remember two things about open pneumothorax: first, if the soldier has not bled to death into his chest, he will die from asphyxia unless treated; and second, when something creates a hole in the chest wall big enough to cause an open pneumothorax, it usually means something big went tumbling through the chest itself. The "big" objects can include high-velocity bullets or fragments, large lower velocity fragments, rocks, pieces of equipment, and even live ordnance. Be prepared for surprises on chest x-ray (Fig. 17.2). Operation may be necessary simply to remove large fragments and contamination. In hopefully rare cases, live rockets or grenades may need to be removed in a bunker with an explosive ordnance disposal (EOD) team at hand, as was done by at least one author of this book.

Treatment priorities remain the same as for all casualties. Although classically listed under "B" in the ATLS "ABCDE" algorithm, open pneumothorax is technically an airway problem – with each of the patient's inspirations, air flows through the hole in the chest wall and into the pleural space rather than through the patient's airways and into the lungs. Hence, a full-blown open pneumothorax can kill a patient nearly as fast as an airway obstruction. The airway may need to be rapidly secured, particularly if the patient is struggling to breathe and hypoxic. Do not fiddle around placing three-sided occlusive dressings, finding the right sized plastic material to create a seal, or trying to tape the dressing or Asherman chest seal on a bloody chest in the hope of avoiding intubation. Once the patient is on positive pressure, the air flow resistance differential between that patient's airways and the

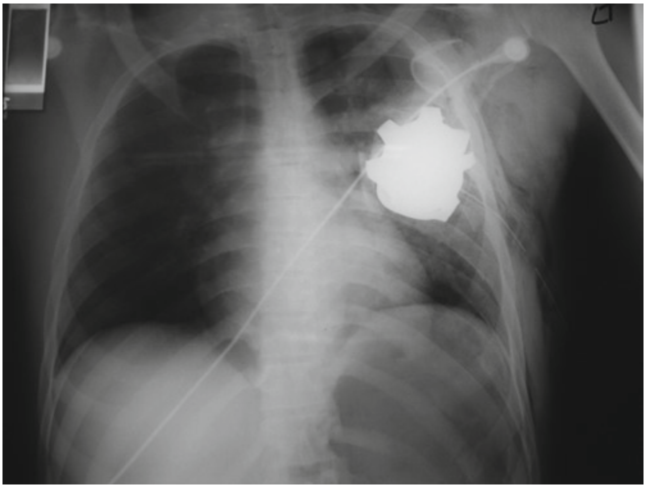

Fig. 17.2 Patient who presented with a chest wall wound and on x-ray was found to have an unexploded rocket-propelled grenade in his chest wall

chest wall injury is eliminated and the airflow problem fixed. Time can then be taken to more completely assess the casualty, place dressings and chest tubes, and obtain a chest x-ray. The chest wall defect can be covered with an occlusive dressing and a separate chest tube placed to suction. The decision to explore the *pleural cavity* can then be based on chest tube output and findings on chest x-ray, as is discussed in the chest injury section. Chest CT scan is rarely needed in the acute setting to make this decision. At a minimum, surgeons should explore the *chest wall defect* to debride devitalized tissue, bone, fragments, clothing, and other wound contaminates and to ensure that intercostal vessels and chest wall muscular bleeders are tied off.

After the casualty's hemorrhage and contamination have been treated, the inevitable question arises – "what the heck do I do with this big hole in the chest?" When in doubt, keep it simple. A blue towel sandwiched between two Ioban drapes makes a fairly sturdy, non-stick dressing that can be placed between the lung and the chest wall defect. Gauze packing into the defect followed by another Ioban dressing will suffice as a sealed, temporary dressing. Be sure at least one well-placed, functioning chest tube is present. Alternatively, for selected injuries negative pressure wound therapy can be applied directly to the wound (Fig. 17.3). Non-adherent white sponge, when available, can be used against the lung, although sterile petrolatum gauze can also be used between lung and black sponge. Again, at least one chest tube should be in place. With this technique, sealing of the lung to completely close the pleural cavity from the wound can be affected, usually in just 3–5 days of negative pressure therapy.

In either case, evacuation of the patient to a higher echelon of care is possible with this temporary chest wall closure. Once the patient is stable, small defects can undergo delayed primary closure in layers based on the quality of tissue present and absence of contamination. Usually, enough chest wall musculature is present to mobilize for a relatively tension-free flap closure over the defect. Larger defects may require a synthetic or bio-prosthetic patch or pedicled myocutaneous flap – these interventions should generally be reserved for higher echelons of care, but you may have to perform these procedures at your forward facility for local national patients.

Fig. 17.3 Use of a negative pressure wound vacuum device to achieve an airtight seal and promote faster healing of an open pneumothorax

Flail Chest

Although this is classically considered an injury of blunt vehicular trauma, many of the mechanisms in modern combat can cause significant chest wall disruption with the classic resultant flail chest segment and underlying pulmonary contusion. Unlike the typical civilian low velocity missile wounds, combat mechanisms such as high velocity missiles, rocket propelled grenades, or explosive devices can all disrupt enough of the chest wall to cause flail. Modern body armor can often turn what would normally be a fatal penetrating chest wound into more of a blunt-type flail segment (Fig. 17.4). Remember that the primary problem is usually not the flail segment; it is the underlying lung injury and pulmonary contusion. The diagnosis is usually readily apparent from close examination of the wound and chest x-ray. Remember that you will not see the typical "paradoxical" motion of the flail segment if the patient is on positive pressure ventilation.

Treat these similar to their civilian counterparts, but be aware that the likelihood of severe associated intra-thoracic injury requiring intervention will be much higher. A chest tube should almost always be placed on the affected side, and early intubation is better than an emergent intubation when the patient tires. Do not put one of these patients on an evacuation vehicle without being sure that their airway is intact and secured. Simultaneously begin administration of pain control agents. An epidural is preferred if you have the expertise and equipment available. Most of these flail segments will stabilize with time, but there is now a growing experience with rib fixation techniques for refractory injuries or severely displaced fractures. This is best left for a higher echelon of care and is not an immediate priority.

Fig. 17.4 Thoracic flail-segment as a result of blunt force transmitted by a high-velocity round deflected by the strike plate of body armor

Diaphragmatic Injuries

Diagnosis

In combat trauma, injuries to the diaphragm are typically found during exploration of either the abdomen or chest – *as they should be.* Extensive work-up with CT scan, MRI, laparoscopy, fluoroscopy, or digital probing of the diaphragm through a chest tube hole are either unavailable or simply have no role in the work-up of penetrating thoraco-abdominal trauma from military munitions. The surgeon attempts non-operative management of these wounds at his peril. Missed bowel injuries, rapid decompensation from delayed hemorrhage, and devastating complications such as biliary-pleural or biliary-bronchial fistulae and herniation of bowel with obstruction or infarction have been the result. The safest course is operative exploration and repair of the injuries found.

As with chest wall injuries, diaphragmatic injuries range in severity from small holes that may heal on their own to massive rents with tissue loss and herniation of abdominal viscera into the chest cavity. The temporary cavitation effect caused by high-velocity rounds can cause large diaphragmatic holes and blow a large amount of stomach or bowel contents across both peritoneal and pleural cavities. The best diagnostic tools the surgeon has to determine the extent of the diaphragmatic wounds are his hands (gently retracting the upper abdominal organs) and his eyes (inspecting the diaphragm). **Inspect both hemi-diaphragms at every exploratory laparotomy!** You would be surprised how many times no one looks and feels up there.

Treatment

Fancy, complicated repairs of small and moderate lacerations, involving interrupted horizontal mattress sutures with pledgets on each side, are unnecessary and time-consuming. Simple, full-thickness running stitches which incorporate the parietal peritoneum and a full thickness bite of diaphragmatic muscle usually suffice (Fig. 17.5). An alternative for more compulsive surgeons is to start a running horizontal mattress stitch, leaving the tail long, then at the "corner" of the wound run a simple baseball stitch back and tie to the initial tail. Heavy, non-absorbable monofilament sutures are the materials of choice. Superior placement of self-retaining retractors, "verticalization" of the diaphragm (retracting the costal margins so that the diaphragm is running almost perpendicular to the operating table), and two-handed retraction on liver, spleen or stomach by the assisting surgeon facilitates exposure and suturing. Remember that the diaphragm is a mobile structure. Do not go down to IT, bring IT up to you (Fig. 17.5). Grab it with long atraumatic graspers on each side of the laceration, and lift it up into the field.

Most of the time, repair of the diaphragmatic injuries can be delayed during the initial operation until hemorrhage and contamination is controlled. Moderate and

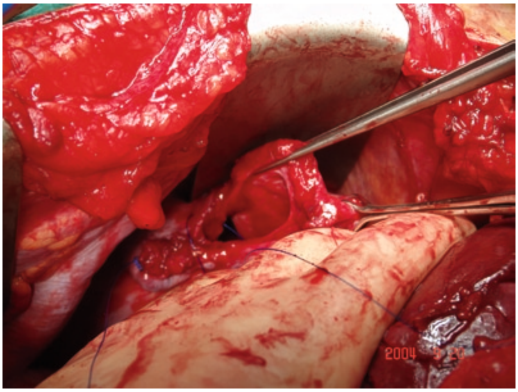

Fig. 17.5 Penetrating wound to the diaphragm being repaired with a running Prolene suture. Note that the diaphragm is highly mobile and is being lifted up and into the wound providing easy exposure

large diaphragmatic lacerations may allow irrigation of the pleural cavity through the defect prior to closure. An ipsilateral chest tube should always be placed. In patients where obvious food-stuffs or stool have been blown into the chest, subsequent formal thoracotomy for thorough wash-out of the contaminated pleural cavity may be required. For casualties whose diaphragmatic injuries were discovered at the time of thoracotomy, the surgeon should usually perform a laparotomy to rule out intra-abdominal injury.

In certain instances, posterior diaphragmatic lacerations allow pooling of blood from the abdomen into the pleural cavity, or allow bleeding from the chest to be pushed into the abdomen with each blow of the ventilator. In the unstable, coagulopathic multiply-injured casualty, this can lead to confusion regarding the source of ongoing bleeding. Is the blood seen welling up from the pleural space coming from the chest, or did it drain up in there from the abdomen? Rapid, temporary closure of the diaphragmatic defect with ipsilateral chest tube placement (if not already done) can rapidly resolve this diagnostic dilemma. In some cases, bleeding lumbar veins or arteries or vertebral body fractures may turn out to be the culprit. In other cases, the blood coming from the chest tube which was originally thought to be from the liver is now discovered to be coming from the lung or heart.

Massive diaphragmatic tears with herniation of abdominal viscera into the chest can confuse FAST exam results, but are usually associated with shock or physical findings of such significance that the decision to go to the OR is not difficult. Attempts to definitively repair these defects in unstable casualties at the initial operation should be avoided. Again, a sterile blue surgical towel sandwiched between two Ioban drapes and sewn to the remnant of the diaphragm edges may provide at temporary solution until hemorrhage and contamination are controlled. The patient will likely need to remain on positive pressure ventilation. Once the patient is stable, the diaphragm can be definitively repaired or reconstructed. Techniques for repair of large lacerations where the diaphragm is torn from its lateral attachments on the chest wall include primary repair by sewing the diaphragm to the rolled up or contracted rim of lateral diaphragm that is usually still present. If this is not possible, then a more complex repair must be considered. PTFE or polypropylene mesh may be used to reconstruct missing diaphragm, but their use is limited in contaminated fields. An excellent option for the avulsed diaphragm is the diaphragmatic transposition procedure (Fig. 17.6). With avulsion injuries and tissue loss, the diaphragm will usually not be long enough to be repaired in its usual position. Take the avulsed lateral border of the diaphragm and transpose it to a new superior position (1–3 rib spaces) using

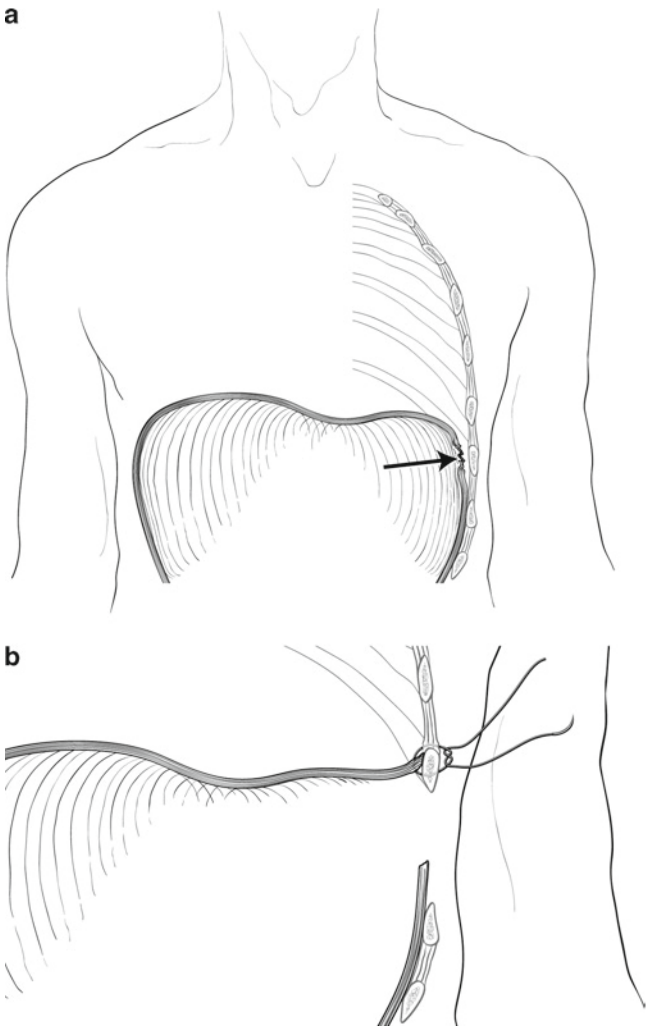

Fig. 17.6 Transposition of the torn or avulsed diaphragm edge (**a**) to a more superior position with suture pexy to the rib (**b**) will facilitate a tension free reconstruction to restore proper chest and abdominal domain

interrupted non-absorbable sutures through the diaphragm edge and around the rib. More complex repairs involving reconstruction of the chest wall and complex flap closures are best done at a higher echelon of care.

Final Points

Chest wall injuries are easily discovered in the trauma bay by physical exam. Diaphragmatic injuries are easily discovered in the OR by direct exam. Neither requires immediate definitive repair, but both need to be addressed at least temporarily during the initial treatment phases and operations. Because of the heavy contamination associated with most combat-related wounds, definitive reconstruction of chest wall defects, particularly with prosthetic devices, should be delayed until the patient is evacuated to higher echelons of care or until the patient is stabilized and contamination controlled.

Chapter 18
Soft Tissue Wounds and Fasciotomies

Peter Rhee and Maj. Joe DuBose

Deployment Experience:

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Maj. Joe DuBose	Chief of Surgery/Trauma Czar, 332nd Air Force Theater Hospital, Balad, Iraq, 2009

BLUF Box (Bottom Line Up Front)

1. Do it in the operating room. Big wounds benefit when you have good lighting, equipment, supplies and anesthesia, and the operating room has these things.
2. Trust your instincts and your and physical exam.
3. Closely examine every wound and the surrounding tissue.
4. Bleeding, contamination control, diagnosis and reconstruction are the priorities of trauma surgery.
5. Prompt removal of devitalized tissue and debris is imperative to prevent local and systemic problems later.
6. There will be more dirt, debris, and foreign bodies in these wounds than you've ever seen, and it may take several OR sessions to get them clean.
7. Leave all wounds OPEN initially. If someone else closed it – OPEN IT!
8. Pulsatile pressure lavage systems are convenient but they can hurt soft tissue and may promote rebound bacterial growth. Use simple irrigation.
9. Vacuum therapy and frequent irrigation and debridement is good.
10. Complete full fasciotomies can save limbs and lives. Not a place for mini-fasciotomies.
11. Closing wounds primarily is better than skin grafting and taking patients to the operating room frequently will help achieve that goal.

The surgeon is not yet born who does not think that he is the one who can close in war a gunshot wound primarily.

Philip Mitchiner, 1939

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University of Arizona, Tucson, AZ, USA

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When you imagine "war surgery", you probably conjure up visions of crashing into the chest or abdomen just in time to save a live. Although very dramatic, this will be relatively uncommon in your combat surgical practice. This chapter is dedicated to what will be your most common operative case in combat – operative management of soft tissue wounds. Thanks to modern body armor and vehicles, many of the previously fatal injury mechanisms are now producing less fatal, but still significant, soft tissue injuries. These injuries are devastating and we rarely see these extensive soft tissue injuries during our training in the US. The garden variety civilian stab wounds, slash wounds, and hand gun injuries are incredibly minor compared to the wounds produced by things like a 50 caliber machine gun, an AK47 round, or more commonly an explosive device. We simply just don't see these wounds routinely in the US civilian trauma centers and thus don't have a developed comfort level with the management and pitfalls. The high velocity stuff is just simply unreal and requires a different set of rules and strategies to optimize your patient's outcome. No amount of reading can completely prepare you for some of these injuries. The goal of this chapter is to shorten the learning curve and have you mentally prepared before you are faced with one.

There are four steps in trauma surgery:

1. Hemorrhage control
2. Contamination control
3. Diagnosis
4. Reconstruction

Whether you are doing a laparotomy or treating soft tissue injuries, the steps and priorities are not any different. Take bleeding wounds and big wounds to the operating room immediately. As a general rule of thumb, being in the operating room with wounds is easier on the patient, the hospital staff, and you. You get the best results by doing a good job and the place to do the best job is in the operating room.

In addition to the operative debridement and management of extensive soft tissue wounds, the need for fasciotomy is also a common reality of modern combat casualty care. While the technique utilized for performing these decompressions is similar to that utilized in civilian practice, the indications and specific concerns differ. Additionally, the austere environment of the deployed setting has afforded us a valuable experience with novel approaches to the subsequent closure of these wounds – experience that we hope to impart to you in this chapter.

Large Soft Tissue Wounds

The most important aspect of initial treatment of any soft tissue wound is to stick to your ABC's. These wounds are frequently overwhelming in appearance and you will find that people have a tendency to focus on the wound and not the patient. Avoid the temptation to focus on what may be the most impressive wound of your life and miss other life threatening issues. Prioritize as you would any trauma patient. If you have ample help and someone else can assess the airway and breathing, then you can address bleeding simultaneously. If you are running the team, then while someone else is trying to control the hemorrhage, you can ensure airway and breathing. You will save many more lives in combat medical care by controlling hemorrhage from a large soft tissue wound than you will by performing an emergent airway.

Once more pressing casualty issues have been addressed and emergent injuries excluded, attention should then be directed at the soft tissue wound. Bleeding from the wound is the first step. Direct pressure is the preferred method in civilian trauma, but in combat trauma it is frequently inadequate and also requires a pair of hands that you usually need for other tasks. A well placed and secured tourniquet is the preferred method for extremity hemorrhage control on the battlefield and in the combat hospital. If the patient arrives without one, put one on in the Emergency Room. For wounds distal to the elbow or knee, the tourniquet can be removed either in the operating room or in the resuscitation area. If there is uncontrollable arterial bleeding, pressure dressing can be applied and the tourniquet should be retightened or reinforced with a second proximal tourniquet (Fig. 18.1). For many of the wounds seen in war time, the wounds are not suitable for tourniquets as they are very proximal (Fig. 18.2). While it might seem tempting to simply irrigate these wounds in the Emergency Department or resuscitation area, we would advise you to avoid this temptation for all but the very smallest of wounds that do not need to be explored.

The rule of thumb is that wounds are highly contaminated. Dirt and debris will always be present. Metallic fragments from the explosive device itself or surrounding objects may be present, particularly when the victim was in a vehicle that gets blown up. You may often find bone fragments in the wound but no bony fractures – these are fragments from bystanders or from the attacker in suicide-bombing type incidents (aka “bioshrapnel”). Decaying tissues and human or animal feces have also been found in explosive devices employed by insurgents to enhance wound infection rates. Everything imaginable can be found in the wounds (Fig. 18.3). In the least, the projectiles and fragmentation components of modern war wounds represent substantial risk for severe infection. Devitalized tissue, if not adequately debrided, will only fuel these infections and contribute to adverse outcome.

General guidance for initial operative intervention consists of three main components: irrigation, debridement and leaving wounds open. Antibiotics should be given right away as empiric therapy. The choice of antibiotic should cover gram-negative bacteria (particularly acinetobacter) as they are much more prominent than in civilian trauma practice. We advise wide coverage for gram-positive and gram-negative organisms in your peri-operative choice. Next you should then focus on irrigation. While high-pressure pulsatile lavage (HPPL) systems are commonly utilized in civilian practice, it is the current recommendation by the Joint Trauma Theater System clinical practice guidelines (JTTS CPGs) that the employ of these devices be avoided. While these devices make the irrigation process easier, there is concern that the use of HPPL is associated with additional trauma to the tissues, creating an environment with a greater abundance of devitalized tissue and setting the stage for more aggressive bacterial re-growth. Several studies have shown higher wound infection and complication rates with pulse lavage compared to standard irrigation. Antibiotic resistant acinetobacter has also been associated with the HPPL. These devices are also relatively expensive and may not be available at

Fig. 18.1 Wounds where tourniquets were applied. Panel (**a**) – bilateral tournaquets applied at groin, both legs amputated. Panel (**b**) – tourniquet not applied due to lack of active blood loss. Panel (**c**) – cloth tourniquet applied above wound

all medical treatment facilities in the area of conflict. For these reasons, the use of bulb suction or gravity-fed systems should be utilized to provide for high volume irrigation of all wounds in a more gentle fashion. Normal saline, sterile water and potable tap water all have similar usefulness, efficacy and safety for this purpose. How much irrigation to utilize depends on the size of the wound. As bacterial loads in the wound will drop dramatically with increasing volumes of 1, 3, 6 and 9 L of irrigation, we advise (as does the current JTTS CPG on the topic) that the following

Fig. 18.2 Wounds that tourniquet cannot be effectively applied. Panel (**a**) – wound created by rocket propelled grenade. Panel (**b**) – improvised explosive device

be utilized as a rule of thumb: 1–3 L for small volume wounds, 4–8 L for moderate wounds, and 9 or more liters for large volume wounds or wounds with evidence of heavy contamination. If the HPPL system is used, it can be made more gentle by putting your fingers over the injecting end and to let the fluid fall into the wound. This turns the HPPL into a high flow low pressure system.

After effective irrigation of the wound has removed all loose debris, you should turn your attention to debridement. Remove all remaining foreign material that is readily visualized or palpated through the wound – do not routinely extend wounds to “chase” a fragment that you might have seen on radiography – it will only create new potential spaces for infection and you may injure another structure in the process. While the degree of debridement will require you as the operating surgeon

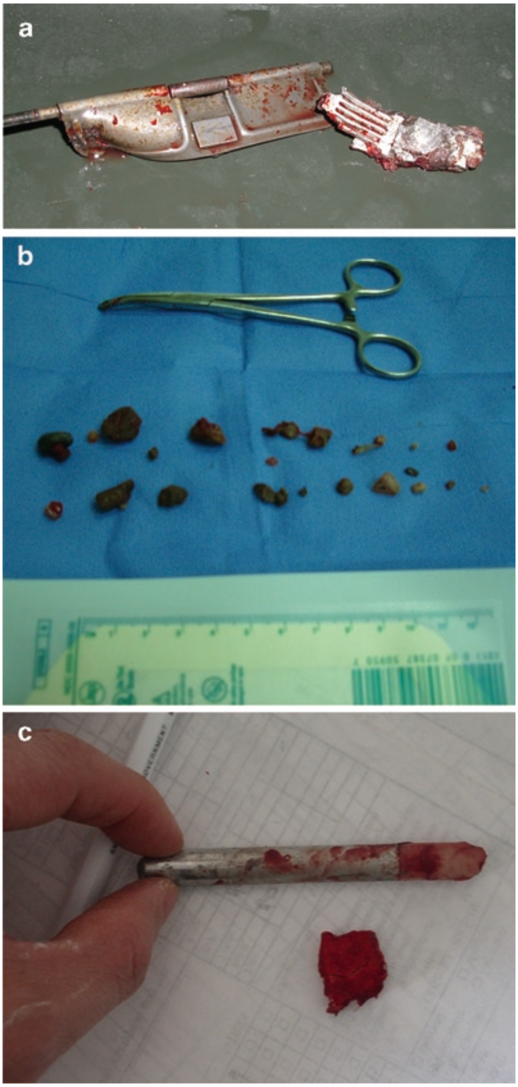

Fig. 18.3 Foreign objects found in wounds. Panel (**a**) – cover of an M-4 rifle. Panel (**b**) – dirt and rocks in wounds. Panel (**c**) – unknown object found in tissue after improvised explosive device

to utilize your own judgment, take care to ensure that all devitalized tissue is removed while at the same time attempting to preserve as much soft tissue as possible for reconstruction at a higher echelon of care or later operations. For muscle, purple or black tissue that does not move with the electrocautery should be removed, but when in doubt you can leave it for the next time the wound is debrided if the wound is left open. There is a widely propagated surgical fallacy about the need for massive wide debridement of high-velocity missile wounds. This is based on erroneous assumptions and distortions regarding the size and extent of injury related to the sonic wave and temporary cavity created, with some authors advocating debridement of a cavity 30 times the size of the projectile. Do not do this; you will only create significant morbidity and cosmetic defects. This has been refuted by both ballistics data and combat surgical experience.

Once irrigation and debridement have been completed, you will be left with the decision of what to do with the now hopefully cleaner and healthier looking wound. Avoid the temptation of closure at the initial operation – there remains the strong possibility that the damage to the tissues has not fully declared itself and that additional debridement will be required at subsequent operation. Dynamic wound vacuum therapy has been revolutionary in the treatment of wounds and if available it has been found to be extremely useful. You have to be very careful however that the wound hemostasis is complete as a vessel that reopens can bleed tremendously with the negative suction. For contaminated soft tissue defects, vacuum therapy is ideal. The utilization of vacuum-assisted closure provides for control and clearance of effluent and promotes early wound healing. Additionally, the use of vacuum therapy and other dynamic approaches limits the degree of wound contraction and increases the likelihood of subsequent delayed primary closure of some wounds. For wounds that will not prove amenable to delayed primary closure, vacuum therapy will promote the development of an early granulation bed that may prove amenable to graft coverage in the reconstructive setting. One additional tip is that stretching of the skin and subcutaneous tissue with sutures over the wound vac helps later closure without skin grafting. **Your planning for closure should start at the first operation**.

Now that you have completed the initial operation, the patient may be transported to the ICU or ward of your facility for continued resuscitation and postoperative care. The question you must then ask is: “When do I take the patient back for subsequent intervention for this wound?” In general for open wounds they should be taken back to the operating room approximately 24 h later. Subsequent irrigation and debridement can be done at larger intervals such as 48–72 h, but if the interval is longer the surprises and disappointments are not worth it. Depending on the length of stay of the patient at your facility and the condition of the wound, some patients may prove amenable to delayed primary wound closure or grafting after just a few operations. You must be mindful, however, that the infection rates in the austere environment of forward care are higher than stateside facilities. For the majority of severe wounds, particularly those involving amputation sites, the wounds should not be closed in theater for casualties that will be evacuating to a higher echelon of care. For those patients that do not fit into this category, utilize sound judgment to balance appropriately aggressive closure with an appreciation of these infectious risks.

You will also need to coordinate carefully with casualty evacuation personnel to determine the optimal timing of subsequent procedures. Remember that your patient may be in the evacuation chain for 48 h or more until they arrive at a facility and can be returned to the operating room. The way to ensure optimal wound care for medical evacuees is to have a policy that all wounds that require multiple operative sessions are taken to the OR for a final washout and debridement within 8–12 h of transfer.

The dressing should also be clearly marked with the date and time of the most recent procedure as you cannot count on medical records to follow the patient.

Small Multiple Wounds

With war wounds, judgment is critical. Judgment comes from experience, and experience comes from mistakes. Fortunately you can learn from the mistakes of others rather than repeating these same mistakes on your own. Remember that the mechanism is very important. High velocity rounds are very different than hand gun injuries. For high velocity rounds the entry and exit are usually obvious, most commonly with a small entrance wound and a large cavity at the exit site. However, some high velocity wounds can be seemingly innocuous at the entry and exit sites but have devastating damage to the underlying tissues in-between. This should be suspected and ALL of these wounds should be operatively explored.

Although many of these injuries will require the soldier to be evacuated from the area, select ones may be managed locally and the soldier returned to duty. The wound depicted in Fig. 18.4 resulted from a close range high velocity round and

Fig. 18.4 Close range high velocity injury to left upper arm. Panel (**a**) – entry site. Panel (**b**) – exit site. Panel (**c**) – closed entry site in 2 weeks. Panel (**d**) – exit site after irrigation and debridment and closure in 2 weeks. Wound closed over penrose and drain pulled out over 10 days

when explored, the muscle damage was impressive and the muscles were dead. This wound was debrided and closed over a penrose drain. Over the next week the drain was advanced out, the wound fully closed and the patient started on physical therapy on the 4th week of injury. By the 6th week the patient resumed full duty. This casualty did not have to be transferred out of theater, and the casualty was able to return to duty to return back with his troops. The patient could have been sent home with a purple heart but he was treated in theater at a level II surgical facility. He remained out of action and on limited duty for 6 weeks but he was able to contribute to his unit and the logistics of evacuating him out and getting a replacement was avoided.

While the big wounds are memorable, the routine far forward was multiple small wounds. These are especially challenging and deceiving. Small fragmentation injuries to the face and neck, arms, legs and hands are extremely common. For civilians and local military, torso injuries from fragmentation are much more frequent due to the lack of body armor. These "peppering" injuries are difficult to assess and seemingly innocuous wounds can hide devastating injuries. As an example, two patients were treated at our facility after a suicide bombing. The first patient has fragment injuries to his entire body, totaling over 100 small wounds. He was found to have no significant injuries and returned to duty in several days. Another casualty was seen and although he was in extremis, he had no obvious external injuries. A chest X-ray showed a massive hemothorax and a small pellet in his right chest. On closer inspection he had a tiny innocuous almost invisible puncture wound in his left chest mid axillary line at the nipple level. The pellet went through his heart and mediastinum. Every patient in an explosive-related incident should get a detailed external inspection and an imaging evaluation for internal injuries, even if their wounds appear small and superficial.

Fasciotomies

Fasciotomy is among the most commonly performed procedures in present theaters of conflict. Subsequently the wounds resulting from decompressions of the extremities will be among the most common you will be expected to manage. You will find that blast injuries account for a considerable number of indications for fasciotomy. The effects of associated fragmentation, crush mechanisms, associated lower extremity fractures, vascular injuries and even blast wave effects themselves may contribute to the development of compartment syndrome of the extremities. The modern advent of early casualty evacuation by air also introduces an environment in which the signs and symptoms of compartment syndrome are difficult to detect. These conditions frequently mandate the more liberal utilization of prophylactic fasciotomy than in civilian practice.

In our civilian practices, we rarely perform prophylactic fasciotomies. We have the luxury of being able to reliably perform continued and repeat examinations, and intervene immediately if needed. You (and your patient) will not have this luxury in combat. For a general rule of thumb, if you suspect a compartment syndrome is present or has a reasonable chance of developing, perform a fasciotomy. Increasing pain remains the most reliable indicator of the need for this intervention, but an exam is not always possible or reliable in patients who are intubated, comatose, or is being transferred rapidly across several echelons of care. If you have performed an extremity vascular ligation or repair, routine fasciotomy should be your default. Burn patients also represent a special scenario. For patients with deep circumferential burns of the extremities, the performance of an escharotomy will in most cases avoid the need for subsequent fasciotomy.

Whenever fasciotomy is undertaken, avoid the temptation to perform lesser procedures. Full decompression of the affected compartments is paramount for success. Mini-fasciotomies look cute, but will earn you the disdain of your colleagues at the next echelon who will inevitably have to extend the fasciotomy to adequately decompress the compartments – and likely have to debride the resultant dead muscle within the compartment. Compartment syndromes can occur in all of the extremities in combat trauma, and you will need to know how to adequately decompress the compartments at each of these locations.

Upper Extremity Fasciotomy

Compartment syndrome of the upper arm is less common than the forearm, but should the upper arm require decompression you can accomplish this through a lateral skin incision from the deltoid insertion to the lateral epicondyle. The upper arm has two compartments, and you should be able to visualize the septum dividing the anterior and posterior compartments through this incision. Make certain to decompress both compartments, while taking care to spare the larger cutaneous nerves and, in particular, the radial nerve which passes through the intermuscular septum from the posterior to anterior compartments just below the fascia.

The forearm has three compartments, the mobile wad proximally, the volar (flexor) and the dorsal (extensor) compartments. Most commonly, effective decompression can be accomplished through a single incision (Fig. 18.5) that begins on the palmar surface between the thenar and hypothenar musculature of the palm and extends transversely across the wrist to arch from the ulnar side of the arm at the wrist to the volar side along the full distance of the forearm. At the elbow, just radial to the medial epicondyle, the incision is curved across the elbow flexion crease. At the wrist, the carpal tunnel is also likely to require release, as is the fibrous band overlying the brachial artery and median nerve at the elbow. This incision allows for soft tissue coverage of the neurovascular structures at the wrist and elbows, and prevents soft-tissue contractures from developing at the flexion creases. In 99% of cases this will also adequately decompress the swollen hand, but if a hand fasciotomy is required then this incision can be extended distally along the thenar eminence.

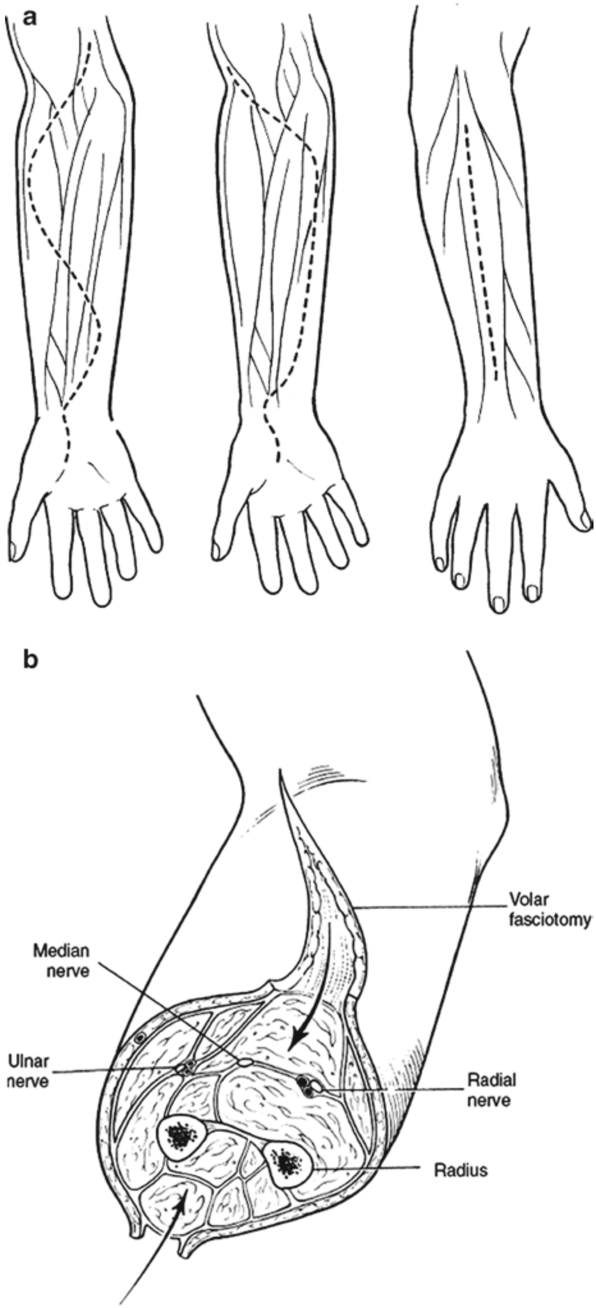

Fig. 18.5 (**a**) Options for forearm fasciotomy incisions. (**b**) Release of the dorsal and volar compartments. (Reproduced with permission from Velmahos G and Toutouzas K. Surg Clin North Am 2002;82:125–141.)

Lower Extremity Fasciotomy

The thigh has three compartments: anterior (quadriceps), medial (adductors) and posterior (hamstrings). The incision for decompression of the thigh extends along the lateral leg from the greater trochanter to the lateral condyle of the femur. After dissection down to the fascia, you must incise the iliotibial band and reflect the vastus lateralis off the intermuscular septum to release the anterior compartment. Then incise the intermuscular septum the length of the incision to release the posterior compartment. Be careful at this point to avoid making the releasing fascial incision too close to the femur, as there are a series of perforating arteries passing through the septum at this location that run posterior to anterior near the bone. Release the medial adductor compartment through a separate incision anteromedially from the groin to just above the knee.

The lower leg (calf) has four compartments that must be adequately decompressed (Fig. 18.6). This is most completely and safely done through the use of two liberal incisions (Fig. 18.7). Make your lateral incision along a line centered between the fibula and the anterior tibial crest from a few centimeters below the knee to the ankle. Once the fascia is identified, make a small incision transversely in the fascia to adequately identify the intermuscular septum. Identification of this septum is the key move for decompression of the anterior and lateral compartments – and failure to do so will result in a missed decompression of one of these compartments (most commonly the anterior). Once the septum has been identified, divide the fascia on either side of the septum the full length of the skin incision. Take care at the superior extent of this incision, as the superficial peroneal nerve will be immediately under the fascia and is easily transected. The second incision is made medially, at least 2 cm medial to the medial-posterior palpable edge of the tibia. At this location, make certain to identify the greater saphenous vein and retract it anteriorly en route to the fascia. Incise the fascia the full length of the skin incision longitudinally to decompress the superficial posterior compartment. Retracting the muscles of this compartment posteriorly will allow access the fascia overlying the tibialis posterior and the deep posterior compartment. Be careful here in extending the fascial incision of this compartment proximally, as the deep posterior compartment contains a number of neurovascular structures that warrant respect.

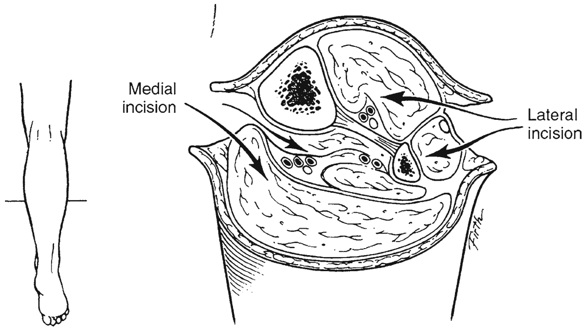

Fig. 18.6 Four compartments of the leg approached through medial and lateral incisions. (Reproduced with permission from Velmahos G and Toutouzas K. Surg Clin North Am 2002;82:125–141.)

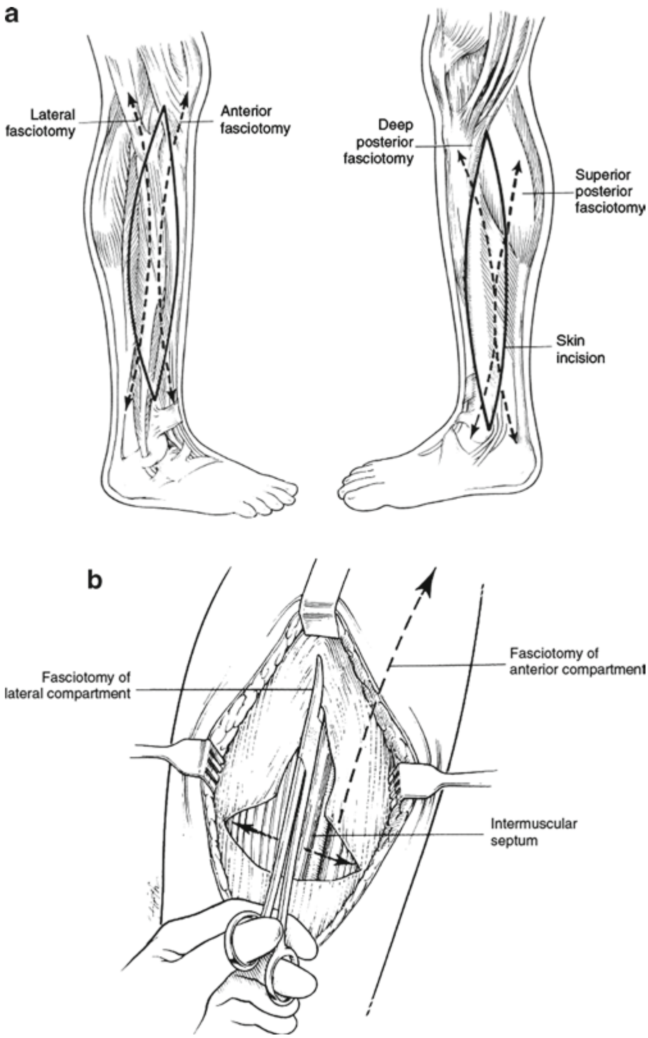

Fig. 18.7 (**a**) Diagram of skin incisions (*solid line*) and fascial incisions (*dotted line*) for a standard four-compartment leg fasciotomy. (**b**) A transverse fascial incision can help clearly define the anterior and lateral compartments to ensure they are both released properly. (Reproduced with permission from Velmahos G and Toutouzas K. Surg Clin North Am 2002;82:125–141.)

How to Manage the Fasciotomy Wound

There are several dynamic ways to address the fasciotomy wound. Vacuum therapy is well tolerated and facilitates control of effluent as the tissues continue to swell. The problem with this approach is that since the dressing changes do not have to be done frequently, there is sometimes a tendency to not take the patient back often. Delay in treating the wounds frequently will result in the skin retracting and making primary closure difficult. This will then ultimately result in split thickness skin graft. While this is acceptable, delayed closure of the skin will prevent subjecting the patient to taking skin off to cover a wound and is cosmetically preferable. There are many methods and devices available to assist in pulling the skin and subcutaneous tissue together. The main problem is that most approaches only pull on the skin edges. For example a favored technique is to use a “roman lace” technique where vessel loops are stapled or sewn at the edge of the skin and then some tension is applied to the open wound. The problem is that this is rarely strong enough to pull the wound closed. If too much tension is applied then the sutures or staples fall out.

Pulley Suture: Trick of the Trade

A trick of the trade which is highly effective in closing any type of wound is what we call the “pulley stitch” (Fig. 18.8). Care has to be taken as this suture is so effective that it can create a compartment syndrome from the skin. This technique is cheap as it only uses a heavy monofilament suture and can even be pre-placed loosely at the original operation so that it can be pulled at the bedside. This suture has been used successfully to close fascia, or any tissue. The principle of the suture is that you use one continuous suture to pull an area of tissue evenly as the sliding suture will distribute the tension equally, as opposed to the vertical mattress where all the tension is on the outer suture and the tissue in between is bunched up. The inner suture only reapproximates the skin edges. The pulley suture will pull tissue far away from the wound while pulling tissue in the middle and at the skin edges as well.

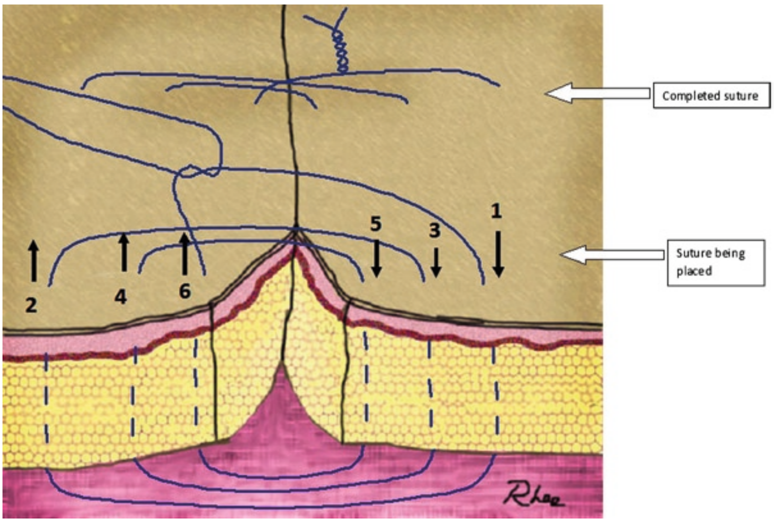

Fig. 18.8 Pulley Suture technique. Large suture is place continuously, 1 FAR – 2 FAR – 3 MIDDLE – 4 MIDDLE – 5 NEAR – 6 NEAR

The wound can be closed over a small penrose drain if needed. After the several pulley sutures have been placed, other simple or running sutures can be placed between or across the pulley suture (Fig. 18.9), or staples can be used. Once the skin has stretched in a day or so, sutures under tension can be cut and the sutures that were not under tension will take over the burden of the tension. This technique has prevented the need of many reconstructive surgeries including skin grafting (Fig. 18.10). To create a pulley suture, start with a simple interrupted suture taking about 2 cm bites of the skin and subcutaneous tissue. The second pass should mirror the first, except now take the bites about 1 cm from the skin edge, in the same line as your first pass. The third pass is again in the same direction, but taking only skin edge to skin edge (2–3 mm). Steady gentle upward traction on the suture ends will now create

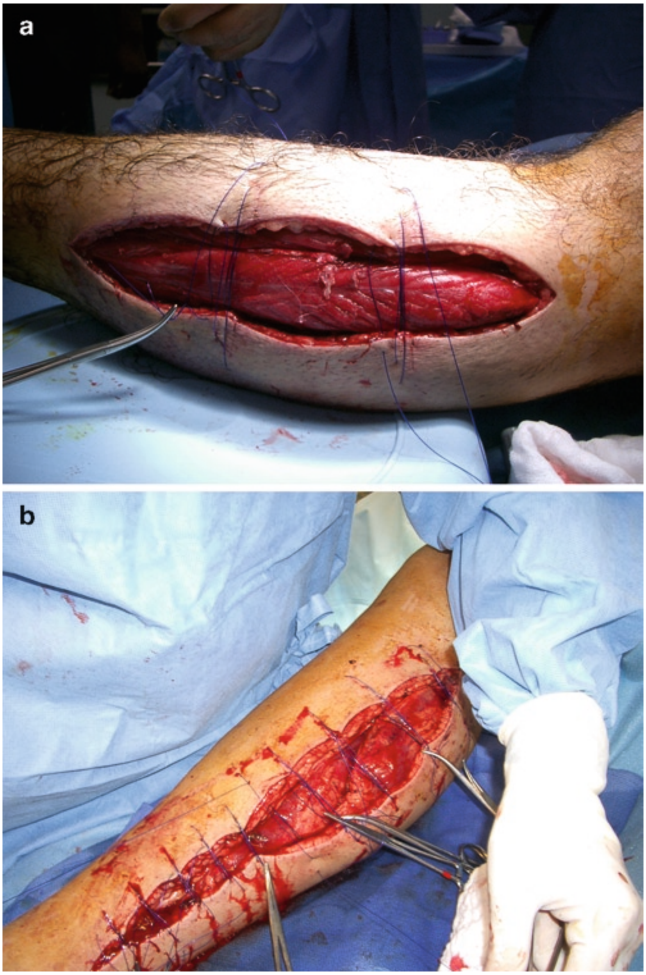

Fig. 18.9 Panel (**a**) – pulley sutures being placed with 2-0 prolene. Panel (**b**) – multiple pulley sutures in place ready to tie

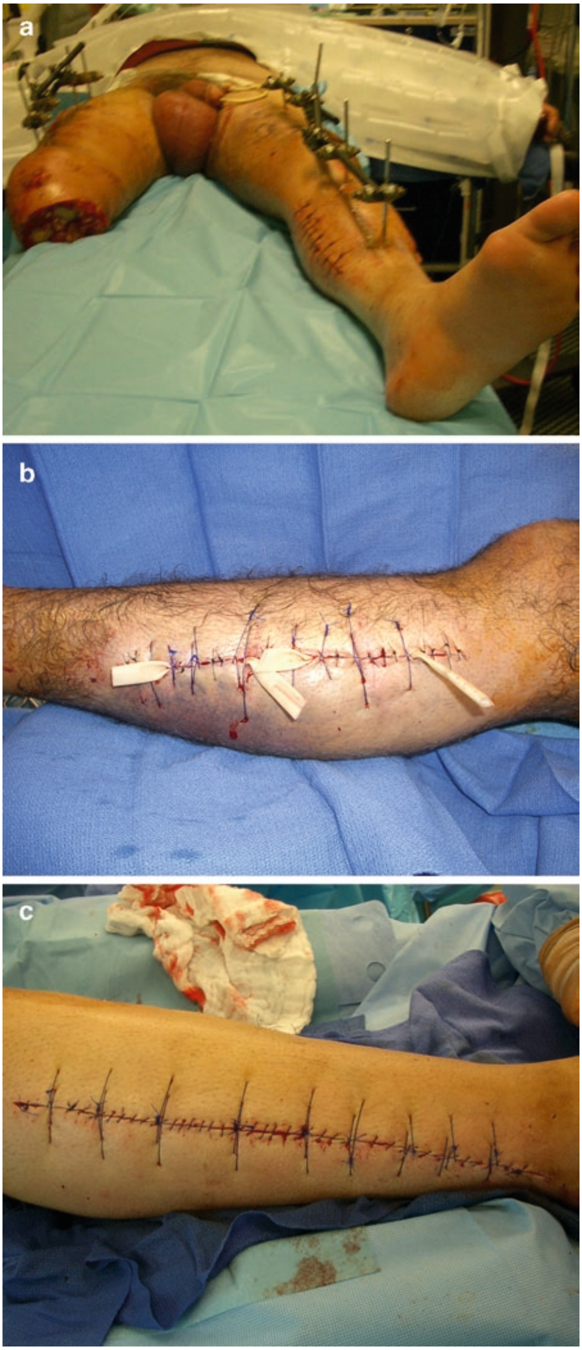

Fig. 18.10 Examples of definitive combat wound closures. Panel (**a**) – fasciotomy wound closed. Panel (**b**) – closed over penrose. Panel (**c**) – skin edges closed across the pulley sutures

significant and distributed force to bring the wound together and allow for easy knot tying under no tension. As opposed to the vertical mattress suture which is “far – far – near – near”, the pulley suture is: “Far – far – middle – middle – near – near”.

Final Thoughts

Soft tissue wounds experienced in modern warfare are considerable challenges that you will frequently encounter. Be aggressive about irrigation and debridement – it will serve you well in avoiding the local and systemic effects of what can develop into devastating infection. But do not be aggressive about closing these wounds at the initial operation! This is one of those lessons that seem to be learned the hard way by newly deployed surgeons, over and over again. Remember that your decision making and technique can set the stage for a successful outcome or a devastating complication, even when dealing with the “simple” soft-tissue wound.

Chapter 19
Extremity Injuries and Open Fractures

Richard C. Rooney

Deployment Experience:

Richard C. Rooney Orthopedic Surgeon, Theater Consultant for Spine Surgery, 28th Combat Support Hospital, Baghdad, Iraq, 2007–2008

BLUF Box (Bottom Line Up Front)

1. Know the extremity anatomy. You will be operating on them more than any other body part.
2. If there is any question about a wound, wash it out.
3. Adequate washouts of combat wounds are not done in the ER. Do them in the OR with proper equipment, lighting, and sedation.
4. Irrigation, debridement and broad coverage of antibiotics are the key to wound management success.
5. Fracture stabilization is the key to pain control and open wound management.
6. Even general surgeons should know how to apply basic external fixation.
7. Decisions about amputation rarely need to be made at the first operation.
8. Get a second opinion if you are debating amputation and document your thought process clearly.
9. You can quickly place a shunt for major extremity vascular injuries prior to fracture stabilization, and then do the definitive repair with a stable bony platform.

A great war leaves the country with three armies – an army of cripples, an army of mourners, and an army of thieves

German Proverb

Although you may have visions of operating night and day in the chest and abdomen in a combat setting, the truth is that you will be dealing with extremity injuries much more frequently than anything else. Because of modern combat mechanisms and improved protective equipment and vehicles, the extremities remain the most vulnerable area to injury (Fig. 19.1). You have most likely dealt with some extremity trauma in the civilian setting, but probably have left most of it to the orthopedic surgeons to manage. In combat you will see extremity injuries unlike anything you have seen

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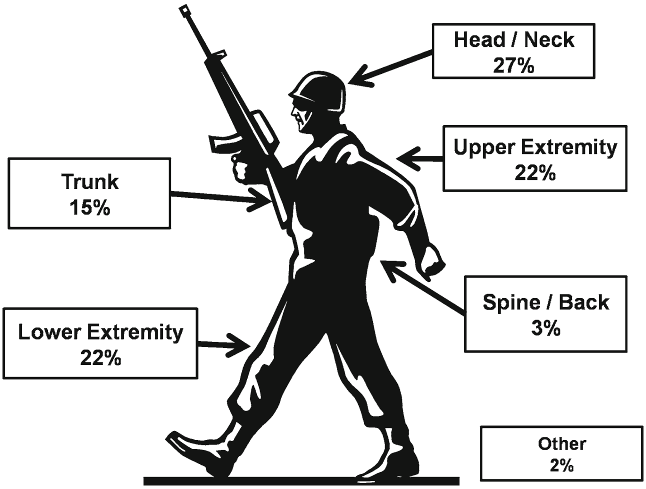

Fig. 19.1 Anatomic distribution of injuries during combat from Operation Iraqi Freedom and Operation Enduring Freedom (Figure courtesy of COL Brian Eastridge, US Army)

in the civilian arena, and you will often not have the luxury of an orthopedic surgeon immediately available to handle it. Review the upper and lower extremity anatomy before you deploy to a combat setting – you will definitely need it.

Combat extremity trauma is not too dissimilar to combat truncal trauma. It is mostly caused by penetrating or blast mechanisms in contrast to the blunt mechanisms of civilian medicine. The principles of open wound management such as irrigation and debridement and early antibiotics are perhaps more important in the extremity than the trunk. The simple reason for this is the presence of bone. Bone is slow-growing and slow-healing and its susceptibility to latent infection is more significant than soft tissue.

Anatomy

The first thing to realize as a general surgeon going into combat is that there will be much more extremity trauma than non-extremity trauma. This is simply from the exposed nature of the extremities. So before you do anything, review your anatomy, primarily the vascular system of the extremities. Arterial injury – not bone, muscle, or tendon injury – is what will cause a patient to die in the field or at your facility. Have a good idea how you will gain proximal control of injuries in the various parts of the extremity. Sometimes this even means going into the abdomen to control groin or high leg injuries and into the chest to control shoulder injuries. You should have a clear idea what is going to be the trigger that prompts you to explore the thorax or abdomen to control hemorrhage.

Fig. 19.2 Patient injured by explosive mechanism with resultant right traumatic below knee amputation and open left tibial-fibular fractures. Left leg and ankle stabilized with placement of an external fixation device

The other surgical anatomy points to review and bring with you are amputation strategies, compartment syndrome releases, and even external fixator placement. Multiple severe extremity injuries are common with combat mechanisms; you may need to use more than one of these techniques on the same patient (Fig. 19.2). If you show up in theatre comfortable with anatomy, the rest of the trauma management will be based on familiar surgical principles augmented by some basic orthopedic expertise that any surgeon can rapidly acquire.

Open Fractures

The keys to success in the management of open fractures are early antibiotics, temporary stabilization, and irrigation and debridement (I&D) until clean prior to closure of wound and definitive stabilization. Early fracture stabilization has multiple benefits in the trauma patient. It will significantly decrease fracture related pain and can often stop bony and soft tissue bleeding. It will decrease the systemic inflammatory response and may provide protection against fat embolization. In addition, the surrounding nerve and vascular structures will be protected from further injury due to the mechanical instability. Appropriate stabilization is absolutely required before you begin mobilization or transportation to another facility.

There is no consensus on timing for open fracture I&D, timing on fixation, amount of irrigation to use, what type of irrigation, or what, when, and how long to give antibiotics. There is no right answer. What makes sense and is supported to varying degrees in the lab is that the sooner you give antibiotics and the sooner you do an irrigation and debridement, the better. Circumstances will likely dictate whether you are irrigating with power equipment or by hand and with what type of antibiotics are available. There is some current evidence implicating high pressure irrigation (pulse lavage) with adverse wound outcomes, so low pressure irrigation should be your first choice.

Historically, for “dirty” open fractures the recommendations are a first or second generation cephalosporin along with an aminoglycoside. In a “barnyard” setting, penicillin is added. Assume that everything in the modern combat setting is a barnyard. 2 g Cefazolin q 8 h, 240 mg Gentamicin q 24 h, and 2 million Units Pen G q 6 h was our pharmacy standard in Baghdad.

It is important to take open fractures or potentially open fractures to the OR and wash them out, stabilize them however you can, and start the antibiotics. There is no practical role for culturing acute fracture wounds. Plan on washing open fractures out every 24–48 h or arranging for that to be done through the evacuation chain. If you are evacuating the casualty to a higher level of care, do a final washout and debridement the day of transfer. Clearly mark the dressing with the date of the last operative debridement so that your colleagues who receive the patient will be aware.

Often one of the puzzling issues is whether a fracture is truly open or is closed with just a local abrasion. There is a fair amount of disagreement regarding how to treat these. In combat, treat them as open fractures until proven otherwise.

Stabilization

There are all sorts of courses and labs set up for the military surgeon to understand external fixation. The fact is that the evacuation chain is so mature that at some point they will see an orthopedic surgeon with a C-arm available prior to going out of theatre. Splinting any extremity in a reasonable anatomic position will serve the purpose of immobilization as well as allow the potentially inexperienced forward-deployed general surgeon to avoid flailing through an external fixator. However, you should be adept at applying a basic external fixator particularly if you are going to be with a far forward unit or in a very remote location. You will NOT always have an orthopedic surgeon available to guide you.

Splinting is very straightforward. The plaster will typically come in strips about 5×30 in. The easiest way I have found to make a splint is to get 10–15 thicknesses and pad it with 3–4 thicknesses of Webril or equivalent cotton padding that comes in rolls. The plaster tears pretty easily when it is dry so figure out what length you need before you get it wet. For instance, for a posterior splint for an arm, you may need to tear the last 5 in. off. Tear or cut it to length. Tear or cut 3–4 thicknesses of Webril for the side that faces that patient and one for the outside. Get room temperature water. Warmer water and normal saline will expedite the plaster cure time but also can create enough heat to burn the patient. Until you get a good idea of the temperature that it will generate, start with room temperature water. As you get more comfortable you may use a little warmer water. The key to slick splint application is having everything set out first. Have Ace wraps ready to go.

Hold onto one end of the plaster in one hand (leave the Webril on the Mayo stand or side – it doesn’t get dipped) and dip the plaster with bare hands in the water. Soak it and then squeeze all the water out. Hold up the splint with one hand from the end and take the other hand and run two fingers down the splint like a squeegee. Do this to both sides to get all remaining water out. Lay the splint on the 3–4 thicknesses of Webril and cover it with the single layer of Webril. This is your splint, ready to be applied and wrapped with Ace wraps.

If you are splinting an arm, have someone hold the arm and the splint at the wrist and support the splint under the tricep while you roll the ace wrap around it. Cut a hole in the ace wrap if you are wrapping over the thumb and if you fold the splint like a cuff at the ends it will look professionally done. Hold the extremity until it hardens. Be careful not to squeeze too hard as it hardens or you will leave indentations. If you feel compelled to place an external fixator, first ask yourself why a splint won't work.

External Fixation

External fixators used in the provisional stabilization of combat casualties are typically "spanning external fixators" which gain control of the unstable segment of the limb by inserting threaded Schantz pins into bone remotely above and below the zone of injury, and connecting these pins with carbon fiber or metal rods external to the body to neutralize the forces across the zone of injury, thereby stabilizing it. The minimally invasive nature of this technique also minimizes the risk of infection due to implanted orthopedic devices and allows access to the wounds for follow on care without having to destabilize the limb. The specific steps required to insert Schantz pins into bone vary according to which system you are using, some require pre-drilling others do not – become familiar with the external fixation devices you will have at your disposal downrange and the recommended insertion techniques. Image intensification is desirable, but not required to apply a resuscitative external fixation device.

Schantz pins must be inserted through safe zones of access to the long bones which minimize the risk to the neurovascular structures. In general, these safe zones include the anterolateral surface of the proximal humerus, the lateral surface of the distal humerus about the elbow, the subcutaneous border of the ulna, and dorsal surfaces of the metacarpals in the upper extremity. In the lower extremity, the anterior and lateral surfaces of the femur are available, as is the anteromedial surface of the tibia, and the calcaneal tuberosity (Fig. 19.3). Despite the relatively superficial nature of these safe zones, major neurovascular injury can occurs at any of these levels in the absence of proper technique. An excellent reference for the deploying combat surgeon who may need to apply an external fixator is *The Atlas for the Insertion of Transosseous Wires and Half Pins*. Get a copy and put it in your duffle bag.

A minimum of two pins are usually required to gain control of a long bone/limb segment. Insert two pins in the same bone above the zone of injury and two below. Meticulous pin insertion technique should be used: the skin is incised sharply directly over the region of intended pin placement, and sharp and blunt dissection is used to gain access to the bony surface. A saline cooled drill bit is used to drill a

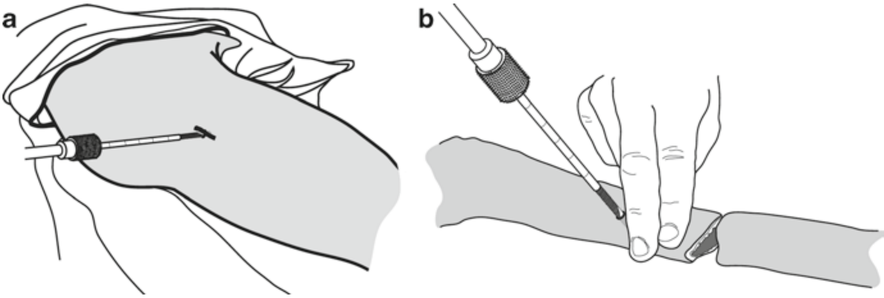

Fig. 19.3 Safe zones for pin placement in the femur (**a**) and tibia (**b**) (Reproduced from Emergency War Surgery Manual 3rd revision 2004, Borden Institute, Washington, DC.)

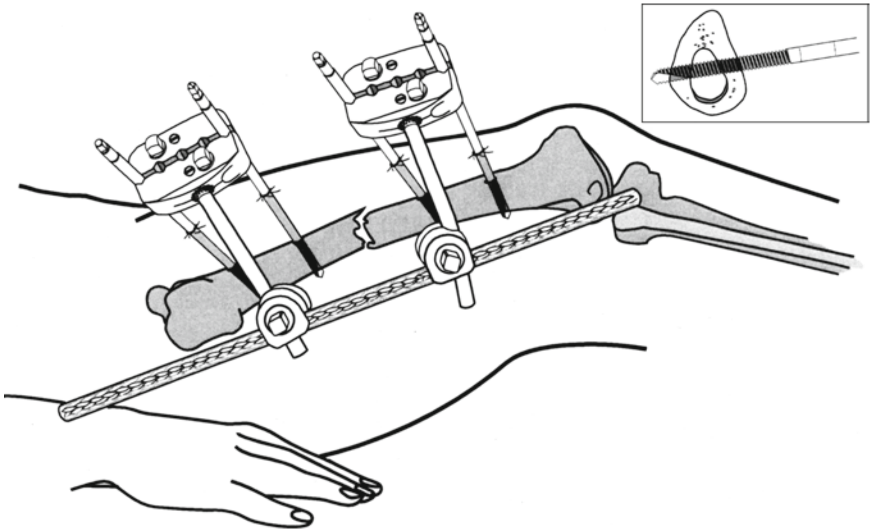

Fig. 19.4 Example of a spanning external fixator stabilizing a femur fracture. The *inset* shows ideal bicortical pin placement (Reproduced from Emergency War Surgery Manual 3rd revision 2004, Borden Institute, Washington, DC.)

pilot hole through a drill sleeve utilized to minimize injury to the local soft tissue (some systems use self drilling half pins). The pin is then inserted through the sleeve deep enough to engage the far cortex of the bone and obtain bicortical purchase (Fig. 19.4). Image intensification is very useful in ensuring proper pin placement and depth, but pins can be placed without fluoroscopy if careful attention is paid to local anatomy and the "feel" of the bone on pin insertion. When the tip of the pin engages the far cortex, increased torque is required to insert the pin further. This information along with the knowledge of thread pitch (and therefore how many "turns" are required to advance the pin into bone after initial engagement) allows for safe bicortical pin placement without image intensification. After two pins are placed in each bone, they are connected with a multiple pin-bar clamp or to a bar isolated to that segment, the fracture reduced (under fluoroscopic control if possible), and the two segments connected with additional bars and bar-bar clamps as required. The sequence of pin placement and frame assembly varies according to the experience of the surgeon, treatment goals, and local anatomy. There are several commercially available external fixator devices, each with their own nuances (Fig. 19.5). Find out which you will have and become familiar with them before you deploy. An important step in the application of spanning external fixators is to verify there has been no change in the neurovascular examination after the injury has been reduced and stabilized. When discovered, the etiology of the change in the neurovascular status must be determined and rectified.

In the lower extremity the most practical insertion position of the pins will be straight anterior. Since spreading out the pins will give you the most stability, put them just above the ankle, just below or above the knee and just below the greater trochanter. The position of the fracture will determine where the intervening pins go. The long bones are about 2–3 cm in diameter so once you engage the anterior cortex make a visual cue so you roughly go in that much. You won't be able to feel the second cortex reliably with the primitive drill that comes with the usual combat orthopedic sets.

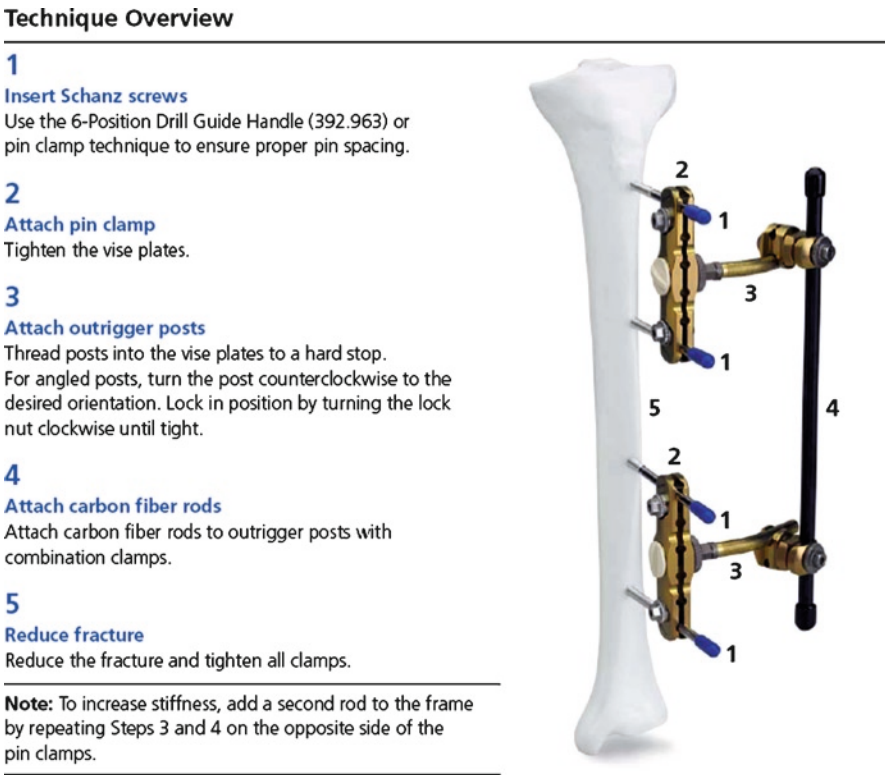

Fig. 19.5 Instructions for applying a simple box external fixation frame (Figure courtesy of Synthes Corporation, Philadelphia, PA)

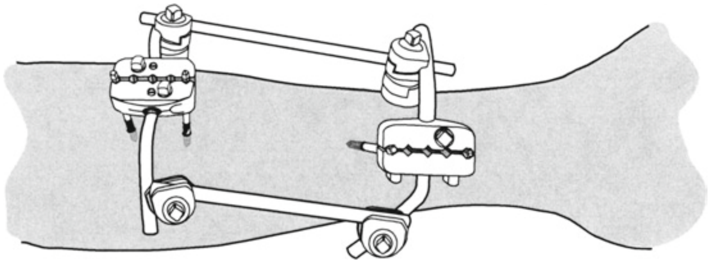

Fig. 19.6 Addition of a second longitudinal bar increases the stability of the external fixator construct (Reproduced from Emergency War Surgery Manual 3rd revision 2004, Borden Institute, Washington, DC.)

Add as many longitudinal bars as you need for stability (Fig. 19.6). Remember that you are doing something in a combat environment to save someone's extremity so don't be frustrated if your contraption looks silly. Keep in mind that almost every extremity can be splinted adequately to evacuate to an echelon of care where someone has all the equipment to apply external fixators appropriately. So keep things simple.

Example fixation situation: Assume you MUST apply an external fixator to an open tibia fracture. It is safe to put all the pins anterior. The tibial crest is thick so don't be alarmed if you have to drill 2 cm just to get through it. Pin spread increases stability so you want to put pins as close to the knee and ankle without putting them into the joint and then as close the fracture as you can without going into the fracture site. Make a little knick in the skin with a knife and spread down to the bone. Put your pin where you want it and tap it gently. This will create a little divot so your pin won't spin away from its target when you start to drill. The pin should be solid when it is in. It should feel like a nail in a solid piece of wood. If it seems like it toggles too much, it may not be in the bone or deep enough. The long bones are somewhere between the size of a broom handle and a tennis racket handle. Make sure you drill the pin into a depth somewhat near this. When the pins are in, pull the leg gently straight so it looks reasonably well-aligned and connect all the bars.

If treating a fractured femur, you can place the pins in safely from the side or straight from front to back (see Fig. 19.3). The lateral pins seem to snag on the gurney so anterior is a little more convenient. One difference with the femur is that the bone is deeper. Near the hip, the easiest way to find your pin location is to feel the greater trochanter. A proximal femur fracture can present significant challenges because the proximal part is hard to get a solid anchor point. In this setting it is probably worth taping the legs together instead.

Arm and forearm external fixation is no different except the bones are smaller. For example, if you have done a vascular repair at the elbow and need it to remain stable, you can apply an external fixator from the humerus to the wrist. The distal radius will accept pins directly lateral (pretty easily on the thumb side) and the humerus will accept pins laterally as well. Use the same placement and drilling technique as the lower extremity. Make a little incision, bluntly dissect to bone and then drill. The radius will need a much smaller pin, however, and the thickness of the radius can be very deceiving. Hence, try to stay as shallow in the bone as possible.

Feel your own wrist to notice how superficial the bone is under the tendons and how superficial the pin will feel if it is barely under the dorsal cortex of the radius.

Compartment Syndrome: A Contrarian Opinion

You will hear a lot about compartment syndrome and fasciotomies before and during any combat trauma deployment. Most of the discussion will be focused on never missing a potential or existing compartment syndrome. You will hear the recommendation to be extremely liberal about doing fasciotomies, particularly on patients with extremity injury who are being placed into the evacuation chain. Compartment syndrome, in my opinion, is talked about too much. In 6 months in Iraq, I performed no more than a handful of fasciotomies and most of them were not on the leg. However, I have also seen some patients with devastating morbidity due to failure to do a fasciotomy. In these cases it was usually clearly indicated, but overlooked by the managing surgeon.

You must know the anatomy and how to do a fasciotomy before you go. This includes both upper and lower extremity (see Chap. 18). The actual fasciotomy is not too difficult. You incise the skin, and the fascia covering the muscle is a very distinct tissue and the plane is very easy to identify. You make a knick in the fascia and slide your Mayo/Metzenbaum scissors or whatever sharp instrument you choose up the length of the muscle belly.

In the upper extremity, it is a little more involved because the incision potentially crosses the elbow and wrist joints. Nevertheless, open the length of the compartment under direct vision and if it looks like a vessel or nerve, don’t cut it. If it looks like a separate muscle belly that is tight, release it. Know the number of compartments in each section of the extremity, and make sure you have addressed them all. The most common missed compartment is the deep posterior compartment in the calf.

Vessel loops and staples are a popular provisional closure technique. Retention type sutures work as well. Again, there is no right answer. The wound is washed out until ready to close which is dictated by swelling and cleanliness. Skin grafting for coverage is not uncommon, but can be avoided in over 80% of cases by appropriate attention to wound management and progressive early closure.

I think there are many more fasciotomies performed than really need to be. I don’t think that this is wrong; it just means that some surgeons have a different threshold. You have to use your best judgment. Fasciotomies are not benign and can often complicate prosthetic fitting so it is not something to done without thought. Also remember that often times the injury itself has done an adequate decompressive fasciotomy, and adding additional incisions will only serve to increase the limb morbidity. If the patient has a relatively normal appearing extremity and benign exam, then fasciotomy is usually not necessary. Even among patients being evacuated – the evacuation system is much faster now and with more medical attention paid to the wounded during the entire process. You patient will not sit for days without medical attention, so you can trust that expert eyes will be re-examining the extremity shortly. If the case is borderline or you have doubts, then either do the fasciotomy or keep the patient at your level for another 24 h to watch them closely before transportation.

Nerve and Tendon

You will frequently encounter injured nerves and tendons during your exploration and debridement of extremity wounds. Sometimes it is difficult to tell tendon from nerve; the best way is to look directly at the cut end (after debriding devitalized segments). Nerves will be yellow-white and contain multiple round fibers while tendons will be blue-white and have crosshatching (like wood). These are typically massive wounds with significant contamination and non-viable tissue, so there is not really a role for immediate primary repair. Tendon repairs can wait until the wound is cleaner, and most combat nerve injuries will be repaired in a delayed fashion. Always leave hand tendon repair for someone with adequate training. Tag the ends of the nerve for easy identification later.

Occasionally you will encounter a very clean and sharp major nerve transection suitable for immediate primary repair and no orthopedic or neurosurgeon immediately available. Common examples are median or ulnar nerve transections (often associated with brachial artery injury). Make sure you align the nerves properly, sharply debride the ends, and reapproximate the epineurium only using fine prolene or nylon sutures (Fig. 19.7). Ensure adequate tissue coverage of the repair and you may need to splint the extremity in flexion to prevent tension on the repair. It will take months to determine the success of repair and ultimate degree of return of function.

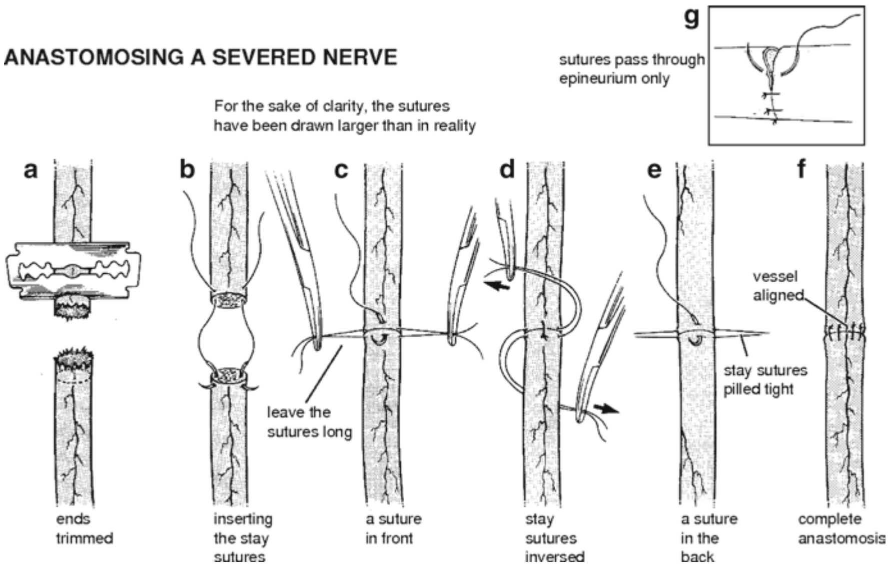

Fig. 19.7 Technique of epineurial primary nerve repair. The ends of the nerve are sharply debrided (**a**), two stay sutures are placed (**b**), anterior (**c**) and posterior (**d**, **e**) approximating sutures are placed, and the anastomosis is completed with multiple interrupted sutures (**f**). Note that sutures pass through the epineurium only (**g**) (Reprinted with permission from "Injuries to Vessels, Nerves, and Tendons" in Primary Surgery Volume 2, German Society for Tropical Surgery 2008, illustration by Peter Bewes.)

Final Thoughts

Don't lose sight of the fact that the first trip to the OR often is for resuscitation and stabilization. Don't prolong a trip in the OR to chase every little laceration and piece of charred tissue. Get them in, get them stabilized and get them out. If they are grossly contaminated you may have to bring them back in 24 h or less. Think of the patient as a whole. There are no gurus of combat surgery. Most surgeons in combat are within 5 years of their residency. It is harrowing and unfamiliar. Prepare, be definitive and do your best

Chapter 20
Mangled Extremities and Amputations

Eric G. Puttler and Stephen A. Parada

Deployment Experience:

Eric G. Puttler   Commander, 102nd Forward Surgical Team, Baquba and Mosul, Iraq, 2004–2005

BLUF Box (Bottom Line Up Front)

1. Damage control principles apply to orthopedic injuries too.
2. There is no reason that you can't operate on the injured extremity while another team is operating on the trunk or head.
3. All amputations or mangled extremities get a tourniquet applied – no exceptions!
4. Remove all debris, foreign bodies, and devitalized tissue at the first operation, and DO NOT CLOSE ANY WOUNDS!
5. Two heads (or three) are better than one if you are undecided about amputating.
6. Be aggressive about attempting limb salvage initially – amputation is better as a delayed decision and with the patient's knowledge and input.
7. Know how to apply a basic external fixator – even if you're not an orthopedic surgeon.
8. The name of the amputation game is preservation of tissue, which will preserve options and function for your patient. Do not do a definitive amputation procedure up front.
9. If there is no advanced orthopedic care available locally, then complex limb salvage on a local national is a bad choice.
10. Similarly, if there is poor prosthetic support then a local national patient may be better off with a poorly functioning but intact limb than an amputation.

"In reality there is no way to separate today's surgery and our practice from the experiences of all the surgeons who have preceded us."

Ira M. Rutkow

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M. Martin and A. Beekley (eds.), *Front Line Surgery: A Practical Approach*,
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Initial Assessment and Resuscitation

With the ongoing improvement in body armor and ballistic helmets, as well as advances in modern combat casualty care, more and more combat casualties will survive following injury long enough to be resuscitated. As such, the severity of extremity injuries among survivors of combat injuries is increasing. Such injuries rarely occur in the context of civilian medicine, even at Level I trauma centers. So the first thing you have to do when you enter a combat zone is realize you are in a combat zone: the game is changed and you need to adapt to a different injury paradigm.

Rule number one is do not get distracted. Traumatic amputees can still die from an unsecure airway if you do. Prepare yourself for the inevitable emotional reaction to the graphic nature of blast injuries. Develop a plan of how to react, and then when you begin treating your first triple amputee, you and the casualty will be better prepared to meet that challenge successfully. Despite being at times massive injuries, familiar and effective treatment strategies can be adapted and used successfully in the combat zone. ATLS is your friend, so after identifying a significant extremity injury, return to the primary survey and manage it initially in that context.

Rule number two is to know where your tourniquets are and how to use them. Limb threatening injuries due to blast will become life threatening the quickest through massive hemorrhage. This can be through characteristic pulsatile bleeding from an arterial injury, or sustained low pressure bleeding from venous sources, injured muscle, and fractures. As opposed to the civilian setting where tourniquets are generally used as a last resort, in the combat setting they should be used early and often. Find out what kind of tourniquets you can expect to be available in your unit and which kinds the units you will be supporting are using – learn how to use them. Also become familiar with their unit SOPs – often you can find a tourniquet on the injured casualty himself in a predetermined pocket or pouch in their combat gear.

Rule number three is to stop the bleeding. A well applied tourniquet will control hemorrhage while doing as little damage as possible. In the pre-hospital setting, hemostatic dressings and direct pressure must be effective to prevent exsanguination in those scenarios. If you have extremity bleeding that cannot be controlled with a tourniquet, surgical control is the only option – get to the OR. **You must begin resuscitation of these patients immediately!** Even if they arrive with no active bleeding and okay vital signs, they have lost a significant amount of blood and plasma volume. A simple rule of thumb used in Baghdad is to give one “code red” pack (4 units blood and 2 units FFP) immediately in the ED for each mangled or amputated extremity. This prevents you from getting behind or from having the patient crash during induction in the OR.

Once acute hemorrhage has been controlled, the casualty has an opportunity to respond to resuscitation and the mangled extremity or traumatic amputation is temporized. Proceed as required to manage ongoing threats to life, but remain mindful of tourniquets that have been placed. Make note of when a tourniquet was applied and be sure this information is passed on to higher echelons of care. Mark your casualty in an obvious way so all care providers know the presence and location of tourniquets, and the time they were placed. Administer tetanus toxoid, a first generation cephalosporin (typically cefazolin), an aminoglycoside (typically gentamycin – remain mindful of shock and the potential for renal impairment), and penicillin (or other agent to cover for anaerobic organisms). If you are in a mature theater, consider tailoring your antibiotic regimen according to historical infection and colonization rates. If the patient is stable enough to go to the OR, then proceed as indicated, if not then remove gross contamination and irrigate with copious amounts of sterile saline. In austere environments, consider a mild soap solution or clean water if sterile saline is not available. Lastly, be sure you have a clear understanding of the appearance of the wounds, and cover them with a clean dressing which should be left in place until the casualty is in the operating room.

In civilian trauma, trauma surgery is generally done in series. The trauma surgeon does a laparotomy and then is followed by the orthopedics team to nail the femur. In combat trauma you must learn to operate in parallel! Prep the entire body, including all involved extremities, and all teams operate simultaneously. It was not uncommon to have four to six staff surgeons operating simultaneously on a severely injured patient. This will save time, resources, and get your patient off of the table and to the ICU rapidly. In the operating room, before removing field tourniquets, apply and inflate a pneumatic tourniquet proximal to the operative field if possible. If needed, prep the tourniquet into the sterile field prior to removal in an attempt to minimize blood loss between the time of tourniquet removal and surgical control. The goal of the first operation is to control hemorrhage and to debride the wound, in that order. As a completion amputation can be considered in the context of both hemorrhage control and debridement, at this time determine if an amputation is required.

Amputation Vs. Limb Salvage

The decision to amputate can be agonizing. The only absolute indication for amputations in wartime surgery is a near complete traumatic amputation with an obviously non-viable distal segment (Fig. 20.1), or the casualty is in extremis and the extremity condition is contributing to their demise. Unfortunately for the combat surgeon, the more common scenarios are not as clear cut. Often, combat surgeons have little experience in complex limb reconstruction for the mangled extremity. Therefore in the forward settings, as long as blood flow can be restored, every technically salvageable limb deserves an attempt at salvage in the theater of operations. This requires a multidisciplinary approach between general, vascular, and orthopedic surgeons. This is especially so in the upper extremities, where the function of a residual limb can far exceed that of a prosthesis. If given the opportunity, frankly discuss the gravity of the limb injury with the casualty, and make no promises as to the ultimate success of your limb salvage efforts. After the casualty has survived his acute injuries and arrived at rear tertiary care centers, the decision to amputate based on reconstructive feasibility and expected functional outcome can be made

Fig. 20.1 Near complete lower extremity amputation with proximal pneumatic tourniquet. Limb salvage is clearly not possible and the amputation should be quickly completed and left open

by those experienced in limb salvage and reconstruction. You cannot decide to un-amputate the limb. While this flies in the face of conventional wisdom in the context of civilian trauma to expedite the decision to amputate, the combat casualty who has a "late" amputation and an opportunity to participate in that decision is often left with the sense that indeed amputation was the best course of treatment, and that every effort was made to salvage the limb prior to amputation.

Three points warrant highlighting. First, scoring systems used to evaluate the mangled extremity do not reliably predict the need for amputation or successful limb salvage. This holds true with the most familiar of these tools, the Mangled Extremity Severity Score, and treatment decisions should not be made on the basis of such a score alone. Second, make the decision to amputate with your available surgical colleagues. Document the reasons for your decision and the nature of your consultations. Third, the distal sensation of the mangled extremity **should not be considered** in the initial decision to amputate or attempt limb salvage. The development of this criterion in modern medicine has grown out of a misinterpretation of the original literature, and has since been discredited as a worthwhile data point: early sensory function of the foot has a minimal impact on long term functional outcome, and acute sensory function is not predictive of long term sensation. Particularly for the patient who has a tourniquet applied or a co-existing vascular injury.

When attempting limb salvage, common scenarios include employing a temporary arterial shunt as required, followed by wound debridement and skeletal stabilization, then definitive restoration of blood flow, with management of compartment syndromes, reperfusion injury, and other soft tissue conditions as indicated. Bear in mind your local capability and context within the theater medical plan, and most importantly the overall condition and stability of the casualty.

Amputation: Forward Techniques

Commonly accepted principles of amputation surgery apply in the combat zone, however blast and other high energy mechanisms often produce wounds where the zone of injury exceeds that which initially might be suspected. The guiding principles for combat amputations are similar to those of limb salvage: control of hemorrhage, debridement of non-viable tissue, stabilization for transport, and infection control.

One of the evolving management principles of wartime amputation surgery in the twenty-first century is the concept of the length preserving amputation. The open circular amputation is no longer preferred or required. In the theater of operations, every attempt should be made to retain any viable soft tissue and bone (Fig. 20.2). With modern reconstructive amputation techniques, irregular skin flaps and soft tissue envelopes can often be augmented with rotational or free tissue transfer and skin grafting to preserve limb length and functional joints. Exposed bone should be left long to provide an internal splint for the soft tissues and to allow for maximum creativity and flexibility in the reconstructive process. You must resist the temptation to amputate at the level of a long bone fracture simply because it is there. Amputation can be combined with osteosynthesis of fractures to maximize limb length and function. A distal amputation may be combined with more proximal debridement and external fixation of fractures to effectively manage a complex injury.

Performing an amputation within the zone of injury requires diligent debridement as described below; wounds should be left open to allow for drainage and to minimize the risk of infection. Remain mindful that this is not a definitive operation; it is the initial phase of reconstruction. The goal is to stabilize the casualty and prepare them for follow on debridement and eventual reconstruction, while preserving maximal tissue and future options.

Fig. 20.2 Traumatic amputation being prepared for initial debridement. Only devitalized tissue should be removed and no attempt made to formalize or close the amputation

Named vessels should be identified and doubly ligated as distally as possible; tourniquet control is recommended to minimize intra-operative blood loss. The skin should be sharply incised preserving as much as possible (skin is a valuable commodity in the reconstruction of traumatic amputations) and the subcutaneous tissues debrided. Peripheral nerves should be identified, incised sharply as required within the wound and tagged with a non-absorbable monofilament suture. Traction and crushing techniques should be avoided. As opposed to the definitive amputation where ideally the nerves retract away from the weight bearing areas, leaving the nerves well identified and accessible in this setting facilitates subsequent surgery. Fascia stripped from muscle and bone should be excised along with non-viable muscle. Muscle viability can be evaluated by its color, consistency, capacity to bleed and, contractility following electrocautery stimulation. Bone should be cut with a saline cooled oscillating saw or Gigli saw, preserving length where possible. Bone denuded of periosteum within the context of a traumatic amputation is likely devitalized, but be conservative with your cuts: retained bone can help splint the soft tissues, resist soft tissue retraction, and can always be cut more proximally at subsequent operations – remember to debride the intramedullary canal. Lastly, do not hesitate to extend the wounds to be sure you have thoroughly debrided the wound; knowledge of common amputation flaps can facilitate the placement of incisions, but atypical flaps in a clean wound are preferred to an ongoing deep infection due to lack of effective debridement. Lastly apply a bulky dressing and consider augmenting this with plaster splints to minimize soft tissue shear and bleeding as well as to assist with pain control. Post-operative antibiotics should continue throughout the evacuation process.

Debridement

The initial surgery often provides the best opportunity for debridement as the soft tissues are compliant and there are no constraints related to protecting prior repaired or reconstructed tissues. It is hard to describe the amount and extent of dirt, bone, debris, and fragments that can be blown into the soft tissues by an explosive device (Fig. 20.3). You should develop and utilize a consistent method of debridement to maximize efficiency and efficacy. Start with cleansing the wound of gross contamination; this can be done in the trauma bay and also immediately prior to the surgical prep. After sterile preparation and draping, inspect the wound and become familiar with the gross anatomy of the injury – develop a plan and extend traumatic wounds to allow exposure of the zone of injury. Then start with the skin and subcutaneous tissues, removing only nonviable tissues, avoid raising skin flaps alone, and preserve perforating blood supply to the skin when possible. Next, extend traumatic fascial defects mindful of underlying peripheral nervous and vascular anatomy to allow inspection of the underlying muscle as deeply embedded fragments can burn deep tissues despite an innocuous superficial appearance; accessible fragments and other ballistic material should be removed, although every piece of metal does not need to be taken out. Finally remove any remaining bone with no soft tissue attachments. An important exception to this rule is peri-articular bone with cartilage. Fragments of bone with articular cartilage should be

Fig. 20.3 Preoperative xray demonstrating the amount and extent of contamination forced into the soft tissues by a typical blast mechanism

retained if the associated joint is being preserved, as reconstructive options are limited for joints with significant articular loss. These fragments should be left in as anatomic a position as possible and covered by soft tissue. If required and the articular surfaces considerable, consider placing these fragments in a subcutaneous pouch remote from the zone of injury (communicate effectively with receiving surgeons). Other bone with soft tissue attachment should be preserved as well. Prior to stabilization, fractures may be displaced to allow access to the deep tissues – subsequent exposure will be limited by provisional and definitive skeletal stabilization.

You may note a consistent theme in this discussion: preservation of viable tissue. While this is an important concept, the wound should look vastly different after an effective debridement than upon arrival. It should be clean, the soft tissue margins and flaps relatively stable, and bleeding controlled. When applying dressings, place deep wicks or Penrose drains to prevent deep fluid collection while avoiding deep placement of isolated sponges that may be missed and left in place during subsequent surgery. Cover the wound with a bulky, lightly compressive dressing, and splints if indicated. Document on the dressing or in the medical records the extent of your findings, the nature of your surgery, and recommendations for the timing of follow on debridement. Repeat debridements are the rule, so preserve tissue of questionable viability at the initial debridement.

Skeletal Stabilization

The stabilization of long bone fractures will minimize ongoing blood loss and damage to injured soft tissues and improve pain control. In the management of fractures sustained in combat, external fixation is the primary provisional skeletal stabilization technique. Often, surgeons not familiar with external fixation techniques are faced with the requirement to use such techniques. If you are preparing to deploy in support of combat operations, it behooves you to become familiar with external fixation techniques as much as possible prior to leaving home. It is also important to remember that external fixation is not the only available technique for fracture management in the combat setting and the effective use of external splinting, whether that is a Hare traction splint or the contralateral limb for a femur fracture, a circumferential sheet or pelvic binder for an unstable pelvis fracture, or commercially available wire, plaster or fiberglass splints for other appendicular injuries is preferred to the errant placement of an external fixation device. External fixation pins placed through peripheral nerves or vessels can preclude successful limb salvage – *primum non nocere.* See Chap. 19 (Open Fractures) for a detailed description of safe pin placement and external fixation techniques.

Definitive Amputation Closure

Although you will rarely do the definitive formal amputation and closure on soldiers, you may be called on to provide definitive surgical care for local nationals or others. After applying the basic principles outlined above for preservation of all available soft tissue, you should have a clean and healthy wound that is ready for formal closure. This will most commonly be either a below-knee or above-knee amputation and at this point is no different than any civilian type amputation closure. When revising a traumatic injury to a definitive amputation, the first consideration is length. With modern prosthetic techniques, there is no longer an "ideal" length, and generally the more length preserved the better. However, adequate soft tissues must be available to cover the bone. Transfemoral amputations should retain as much of the femoral diaphysis as possible with the soft tissues available. Transtibial amputations should be through viable bone, although it may be in the zone of injury, preserving one third to one half of the tibia, and avoiding amputation in the distal one third to one quarter of the tibia.

Transtibial Amputation Technique: Long Posterior Myofascial Flap

Carefully plan out the skin incisions by first determining the anterior to posterior diameter of the leg at the level of the tibia cut (Fig. 20.4). The anterior flap is drawn from a point slightly more posterior than half the diameter of the leg. Mark the anterior apex of the anterior flap in the midline approximately 1 cm distal to the level of the tibia cut. The length of the posterior flap is the anterior to posterior diameter of the leg plus 1 cm. Mark the medial and lateral extensions of the posterior flap, then connect these markings with a transverse posterior line at the

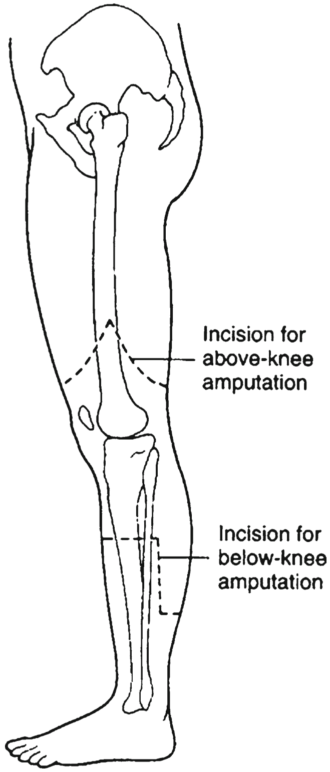

Fig. 20.4 Standard incisions for lower extremity amputation creating a long posterior myofascial flap for below knee amputation and a "fish-mouth" flap for above knee amputation. Combat amputations often require modifications with whatever amount and shape of tissue is available (Reprinted with permission from "Lower Extremity Amputation" in Operative Surgery Manual 1st edition, Khatri ed., 2003 Elsevier Corporation.)

distal end of the flap. Make definitive incisions through the skin, subcutaneous tissues and crural fascia to avoid devitalizing the margins of the flap. Ligate the saphenous vein and transect the saphenous nerve sharply. Identify and doubly ligate the anterior tibial vessels after separating them from the deep peroneal nerve which lies adjacent to the vessels on the anterior aspect of the interosseous membrane. Apply gentle traction to the deep peroneal nerve and divide it sharply, allowing it to retract into the proximal soft tissues. Similarly divide the lateral compartment musculature at the same level, identifying the superficial peroneal nerve (between the muscle bellies of the peronei proximally) and divide it sharply after applying gentle traction.

`Incise the tibial periosteum at the level of the proposed cut and cut the tibia transverse to its long axis with a saline cooled oscillating saw or Gigli saw (Fig. 20.5a). Similarly cut the fibula transversely. Apply tension to the distal segment and remove it by elevating the flap from the posterior surfaces of the bones, leaving the deep and superficial posterior musculature with the posterior flap. Isolate the muscle bellies of the deep posterior compartment, the peroneal and posterior tibial vessels, and the tibial nerve (Fig. 20.5b). Doubly ligate the arteries and ligate the veins after separating them from the nerve which is subsequently

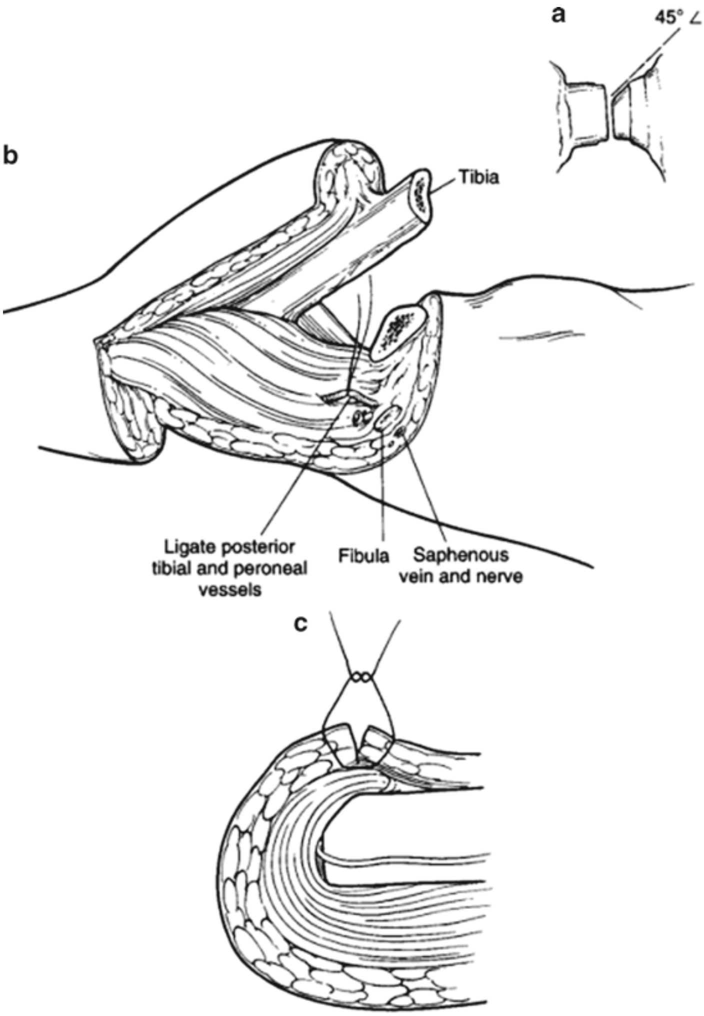

Fig. 20.5 Basic technique for below knee amputation. (**a**) Trans-tibial cut and 45° bevel; (**b**) Vascular ligation and soft tissue transection leaving long posterior myofascial flap; (**c**) Final fascial and skin closure (Reprinted with permission from "Lower Extremity Amputation" in Operative Surgery Manual 1st edition, Khatri ed., 2003 Elsevier Corporation.)

divided under gentle tension. Transect the muscle bellies of the deep posterior compartment at or just distal to the tibial cut. Bevel the anterior surface of the tibia with the saw starting at the cut surface of the bone just anterior to the medullary canal, angling approximately 45° anteriorly and exiting the anterior tibial cortex approximately 1 cm proximal to the original bone cut. Smooth the cut surfaces of the tibia and fibula with a rasp. Irrigate to remove all bony debris and ensure surgical hemostasis.

Closure begins by securing the posterior flap to the tibia (myodesis). This is done by suturing the investing muscular fascia at the end of the flap to the anterior periosteum of the tibia with heavy (0 or #1) absorbable suture. If the tibial periosteum is inadequate, then the flap can be secured through drill holes in the anterior tibia on either side of the anterior tibial crest. Place a drain deep to the flap. Securely close the crural fascia and subcutaneous tissue to allow for a tension free skin closure on the anterior leg rather than at the end of the stump (Fig. 20.5c).

Transfemoral Amputation Technique

Equal anterior and posterior flaps are described here (Fig. 20.4), but other skin flap variations exist. Measure the anterior to posterior diameter of the limb at the level of the proposed bone cut. Mark the apices of the flaps in the midposition of the thigh medially and laterally. The length of the anterior and posterior skin flaps are one half the diameter of the thigh plus 1 cm. Incise the skin, subcutaneous tissue, and deep fascia definitively. Divide the quadriceps muscle at its insertion into the patella, and reflect the vastus medialis off of the intermuscular septum. Identify the adductor magnus tendon at its insertion on the adductor tubercle and detach it, tagging it with heavy suture for later myodesis. Reflect the adductor proximally and identify the femoral vessels at Hunter's canal for ligation. Identify the sartorius and medial hamstrings, and divide them 2 cm longer than the proposed bone cut. Divide the biceps femoris at the level of the proposed bone cut. Identify the sciatic nerve in the posterior compartment of the thigh, apply gentle traction, ligate it with absorbable suture, divide it sharply and allow it to retract into the proximal soft tissues (Fig. 20.6a).

Expose and isolate the distal femur and cut it with a saline cooled oscillating saw or Gigli saw perpendicular to its long axis. Remove the distal segment and ensure hemostasis, irrigate to remove bony debris. Drill four unicortical holes in the distal femur. The first is anterior and 1.5 cm proximal from its cut surface, and the others migrate proximally and laterally a similar distance. Pass heavy nonabsorbable sutures through these holes, and use these sutures to perform a myodesis of the adductor tendon which is secured around the end of the femur with the limb placed in maximum adduction. The medial hamstrings are passed around the end of the femur and attached also via these drill holes, or to the posteromedial aspect of the distal femur by sewing them to the adductor tendons. Additional sutures are placed in the soft tissues to further secure the myodesis as needed and to stabilize the distal femur in the muscle mass (Fig. 20.6b). The quadriceps is drawn over the end of the femur and its fascia is sewn to that of the hamstrings with the hip maximally extended to avoid creating a hip flexion contracture. Deep drains are placed and the superficial fascia and skin are closed in a similar fashion as described in the transtibial amputation technique (Fig. 20.6c).

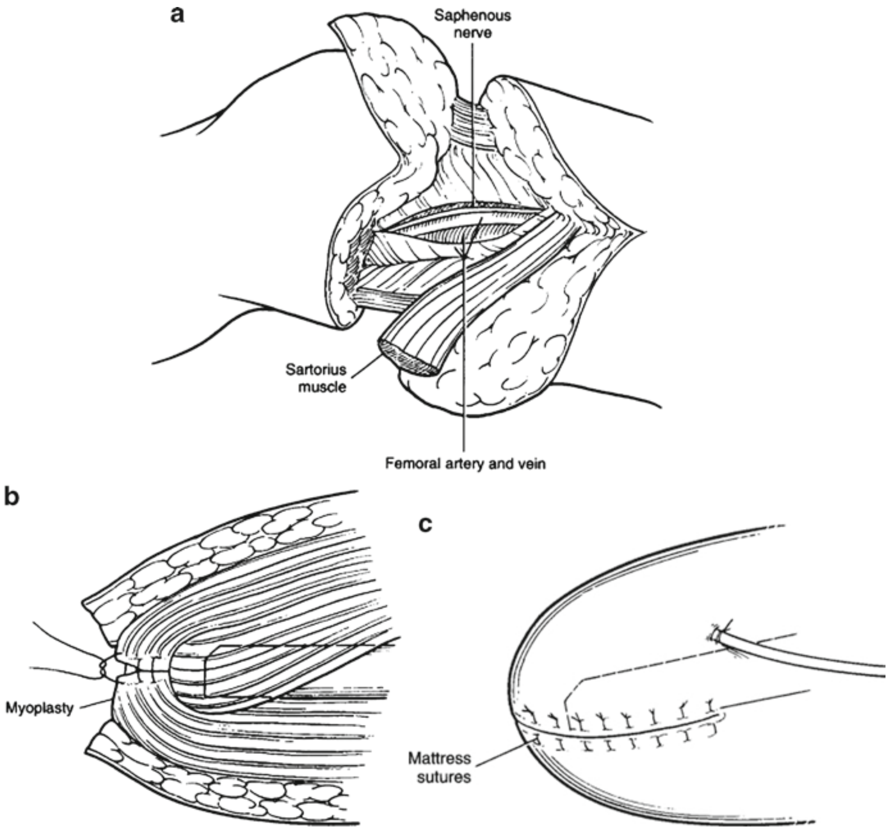

Fig. 20.6 Basic technique for above knee amputation. (**a**) Vascular control and division of thigh musculature; (**b**) Midline myoplasty which can be facilitated with suture fixation to the femur; (**c**) Final fascial and skin closure (Reprinted with permission from "Lower Extremity Amputation" in Operative Surgery Manual 1st edition, Khatri ed., 2003 Elsevier Corporation.)

Care for Local Nationals

Surgeons supporting combat operations in the twenty-first century must be prepared to care for enemy combatants, local and third country nationals, allied forces and civilian contractors in addition to directly supported military units. Generally speaking allied forces and civilian contractors can be treated using algorithms similar to wounded US Soldiers as they can be expected to be evacuated to modern medical facilities eventually. For enemy combatants and local and third country nationals, however, the deployed military medical capability may exceed the capabilities for the host nation and therefore this population may often be definitively managed by deployed surgeons.

When treating mangled extremities in this patient population, you must become familiar with the local medical capability and the rules of engagement for the care of these casualties, in addition to your own capability for managing such injuries, both in terms of your own expertise, facility limitations, and the availability of consultants and subspecialty care. It does no good to embark on a complicated limb salvage plan if there is no opportunity to provide or arrange for required follow on care such as flap coverage, delayed bone grafting, or sophisticated reconstructive techniques. At the same time, access to artificial limbs may be non-existent and an otherwise very functional amputation can be totally disabling without prosthetic support in a third world country. These decisions are hard to make and there are no right answers, but suffice it to say, you may embark on limb salvage under less than ideal situations to salvage an extremity with significantly compromised function, or you may choose to amputate a limb that may be reconstructable with techniques which are not available. These challenging scenarios can also be the most rewarding for creative thinkers with imaginative treatment strategies and diligent technique. In order to maximize your patient's functional outcome, you must be familiar with local resources and then operate within those constraints and have realistic goals appropriate for your patients given their cultural biases, expectations, and norms.

Final Thoughts

You do not exist in a vacuum. Don't be a cowboy in austere environments if your casualty can survive evacuation to the next level of care. Be familiar with the theater medical treatment and evacuation policy; you are part of a team and a system that is designed to operate cohesively. The better you fit in to the big picture, the more useful you are to your casualty and to the supported commands. Reassess bleeding if a tourniquet has been placed but evacuation is not expected soon. The indications for tourniquet application are greatly expanded as discussed above. Evaluate the patient and consider releasing it in the absence of significant bleeding or hard signs of vascular injury. Leave the tourniquet loose on the limb for transport so that it can be rapidly reapplied en route if needed or consider reapplying the tourniquet yourself just prior to loading if you have a high index of suspicion.

Chapter 21
Peripheral Vascular Injuries

Charles J. Fox

Deployment Experience:

Charles J. Fox Department of Surgery, 10th Combat Support Hospital, Baghdad, Iraq, 2006

BLUF Box (Bottom Line Up Front)

1. Early initiation of damage control resuscitation concepts is crucial to performing a successful simultaneous vascular reconstruction.
2. A vascular assessment should begin in the admitting area using physical exam and a handheld continuous wave Doppler device.
3. A CT angiogram may be useful for cervical or truncal vascular injuries to plan the best approach but is rarely necessary for extremity vascular injury.
4. Pre-hospital tourniquets should be augmented with the pneumatic type and should only be removed in the operating room once the patient is stable and the surgeons are prepared to control hemorrhage.
5. Vascular repairs often require massive transfusion, therefore temporary shunting with delayed repair should be the default at far forward surgical facilities.
6. A second surgical team can save time by placing external fixation and performing saphenous vein harvests or fasciotomy.
7. A vein interposition graft is durable when there is adequate muscle coverage; otherwise a longer bypass tunneled out of the zone of injury should be chosen to prevent desiccation or delayed rupture.
8. Don't forget the vein – ligate if necessary, but shunting or repair of major venous injuries will improve outflow and augment your arterial repair.
9. Trust your physical exam, and remember that it is hard to improve upon a palpable pulse and perfused limb.

It is better to see the outside of the vessel before you see the inside

Unknown

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Vascular trauma in the military has special importance as combat-related injuries to major vessels offer unique surgical challenges and comprise the majority of potentially preventable deaths on the modern battlefield. The front lines of a battleground are predictably dirty, noisy, and located in predominantly harsh climates. You will routinely perform surgery in tents or abandoned buildings that lack suitable light and ventilation. These austere conditions demand early deliberate preparation to ensure successful management of vascular wounds. Lessons learned during US military operations continue to advance the practice of vascular trauma surgery and now translate into the current recommended surgical practices. Despite the fact that Vascular Surgery has become largely separated from General Surgery, all military surgeons must be well versed in basic vascular anatomy and reconstruction techniques. The majority of combat vascular injuries are not being handled by Vascular Surgeons, and you are unlikely to have one available to guide or assist you. Be prepared, you can be the difference between limb salvage or loss.

Initial Assessment & Operative Planning: Peripheral Vascular Injury

The effectiveness of early tourniquet application observed in Iraq and Afghanistan has led to doctrinal changes that have produced a surge of patients presenting with vascular injuries that in past conflicts would never have reached a field hospital alive. Therefore, during your deployment you will find yourself fixing more vascular injuries than you have ever imagined. Optimal management requires proper planning and recognition of the essential priorities necessary to prevent immediate hemorrhagic death. Explosion-associated injury, the most common vascular wounding pattern, involves fractures, thermal injury, and embedded fragments over a majority of the body surface. Following immediate airway control, attention is directed at controlling hemorrhage and obtaining vascular access. A volume depleted patient may not always manifest active arterial bleeding at the time of admission. Pre-hospital tourniquets should nonetheless be inspected and readjusted, augmented, or replaced once the resuscitation restores adequate peripheral perfusion.

Recognizing the need for vascular reconstruction at the time of the trauma admission is crucial for success as indecision and progressive ischemic burden can result in ultimate graft failure and subsequent limb loss. Most of the extremity injuries involve fractures and large soft tissue wounds that can make the diagnosis by physical exam alone very accurate. Radiographs can provide early clues that extremity vascular injuries exist and you should take a close look at the plain films as you enter the admitting area. For example, supracondylar femur and tibial plateau fractures are frequently associated with injuries to the distal femoral and popliteal artery. These are among the most common lower extremity vascular injury patterns that you will encounter. Deformed extremities are straightened and the onset of additional hemorrhage is controlled with direct pressure, gauze packing, hemostatic dressings, or additional tourniquets. Alternatively, in stable patients without active bleeding, pre-hospital tourniquets should be carefully loosened to determine the degree (if any) of vascular injury.

A Doppler assessment is advised to confirm the absence of pedal pulses and to perform an Ankle-Brachial Index when possible. A patient assessment done in concert with an orthopedic surgeon will facilitate the necessary discussion regarding the sequence of the operation, and preferred techniques for external fixation that best aid in the anticipated vascular exposure. The usual proper sequence should be (1) stabilize the patient, (2) stabilize the fracture, and (3) repair the vascular injury. Important information to relay to the entire operative team should include ideal patient positioning, the plan for vein harvesting in a contralateral extremity, and the desire for a C-arm or arteriography. Special instruments located in "peel packs" can ease the apprehension of not having the favored instruments when needed quickly. The earlier you relay this information to the OR, the easier and faster your case will be.

Surgical Management: General Tips & Techniques

A dedicated two-team approach is recommended for the surgical management of military vascular injuries. For extremity injury this practice reduces ischemic time as the primary team may be preoccupied with thoracotomy or laparotomy to control hemorrhage or other damage control maneuvers. Do not hesitate to involve a second team as they can be used to apply external fixation, perform fasciotomies, begin a peripheral vascular exposure, or harvest vein from a non-injured or amputated extremity (Fig. 21.1). It is important to take some extra "careful" time when doing the vein harvest. You should always caution your assistant on the potential for

Fig. 21.1 Three teams operating simultaneously on a patient with orthopedic injuries and a vascular injury at the Combat Support Hospital in Baghdad

injury to the saphenous vein when performing a fasciotomy. Position the patient to enable unimpeded access to another body cavity or limb in the event of unexpected deterioration or need for additional vein harvesting.

Initial control of hemorrhage is often accomplished by digital occlusion using an assistant's hand prepped directly into the bleeding wound bed with betadine spray. This is followed by a careful dissection proximal and distal to the site of injury. Balloon catheters may also tamponade hemorrhage when a tourniquet or manual pressure is not effective, but blind insertion of surgical instruments can be unproductive or harmful and is discouraged. Tourniquets are left in place until the anesthetist has sufficient time to resuscitate the patient. You may find that the transected vessel ends can be difficult to identify in the destroyed tissue. Although often thrombosed at the time, these vessels must be found and ligated because they will re-bleed later after the patient is resuscitated. Retrograde advancement of a Fogarty catheter from an uninjured distal site can also be used to locate the transected artery in a horrific wound that is no longer bleeding. When making a decision to amputate or salvage an extremity, you should consider the patients' condition, extent of injury, and your willingness to commit the patient to the necessary definitive orthopedic care and physical rehabilitation. No one situation or scoring system can replace the surgical judgment developed by an experienced team.

A primary end to end repair is preferred when lateral sutures cannot repair the injured vessel. Advantages of this repair include a single anastomosis and use of autologous tissue. Dividing nearby branches may gain some length in non-calcified vessels, but this repair should be both expedient and tensionless. If the vessel has not been transected, realize that the ends will retract significantly once you complete the division, so it can be helpful to place several stay sutures that traverse the injured area to hold it in place and facilitate the anastomosis (Fig. 21.2). A complete debridement of any disrupted tissue is an essential step of the repair, and sacrifices

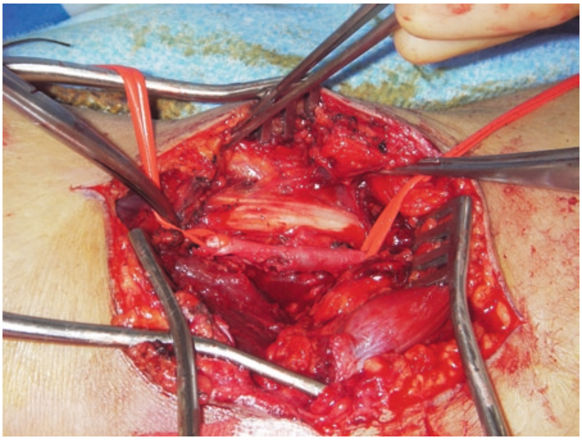

Fig. 21.2 Fragment injury to the superficial femoral artery. This should be amenable to primary end-to-end repair, but beware that the ends will retract significantly once you complete the transection and debride the injured vessel wall

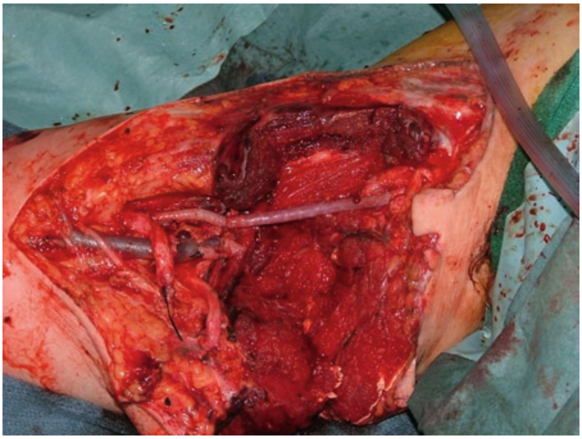

Fig. 21.3 Cavitary wound with significant tissue loss. Femoral artery has been repaired with an interposition graft but obtaining adequate soft tissue coverage of the vessels will be a challenge

made to avoid an interposition conduit should be keenly resisted. The complexity and additional operative time required for vein harvest and interposition grafting or bypass should be appreciated, and the final operative plan and estimated time should be communicated early to the entire operative team. The saphenous vein is the preferred conduit for military vascular injuries. The poor historical results of prosthetic material when used in contaminated war wounds is the justification for this approach. In my experience, prosthetic grafts placed in larger vessels with good muscle coverage have been used successfully. I have used prosthetic grafts for "clean" subclavian and carotid wounds. However, inferior long term patency of prosthetic materials and the potential for infection in war wounds have restricted its widespread use in combat-related extremity wounds. Prosthetic may also be used as a temporary repair, with a plan for subsequent re-exploration and replacement with vein graft if necessary.

Military munitions produce large cavitary wounds with numerous disruptions of the skin and loss of underlying muscle that may thwart attempts to achieve suitable graft coverage (Fig. 21.3). When you are confronted with this situation, a longer vein graft tunneled completely around the zone of injury should be chosen over a shorter, poorly covered vein interposition conduit. Appropriately applied external fixation will take this issue into consideration, and this is an important subject to discuss before fasciotomy incisions are made. Devitalized tissue is excised and irrigated under low pressure, with careful evaluation of muscle tissue for viability. A lengthy and meticulous debridement at the outset is not necessary as these wounds look much better in a few days after subsequent washouts and vacuum dressings.

Ballistic trauma can transmit kinetic energy and result in intimal injury well beyond the transected arterial segment. Therefore, perform your debridement with a great deal of concentration focused on the quality of the luminal surface and strength of the arterial inflow relative to the patient's hemodynamics. When necessary, a Fogarty catheter should be carefully advanced as pre-hospital tourniquets and incomplete heparin dosing in trauma may result in thrombus accumulation proximally. In military trauma, lack of adequate lighting, fine surgical instruments, desired monofilament sutures, and loupe magnification may hinder the careful tissue handling that is crucial to a successful vascular operation. To overcome these expected obstacles, a four quadrant, heel to toe anastomosis that is well-spatulated is the easiest method to teach and perform in difficult situations (Fig. 21.4). Small Heifitz

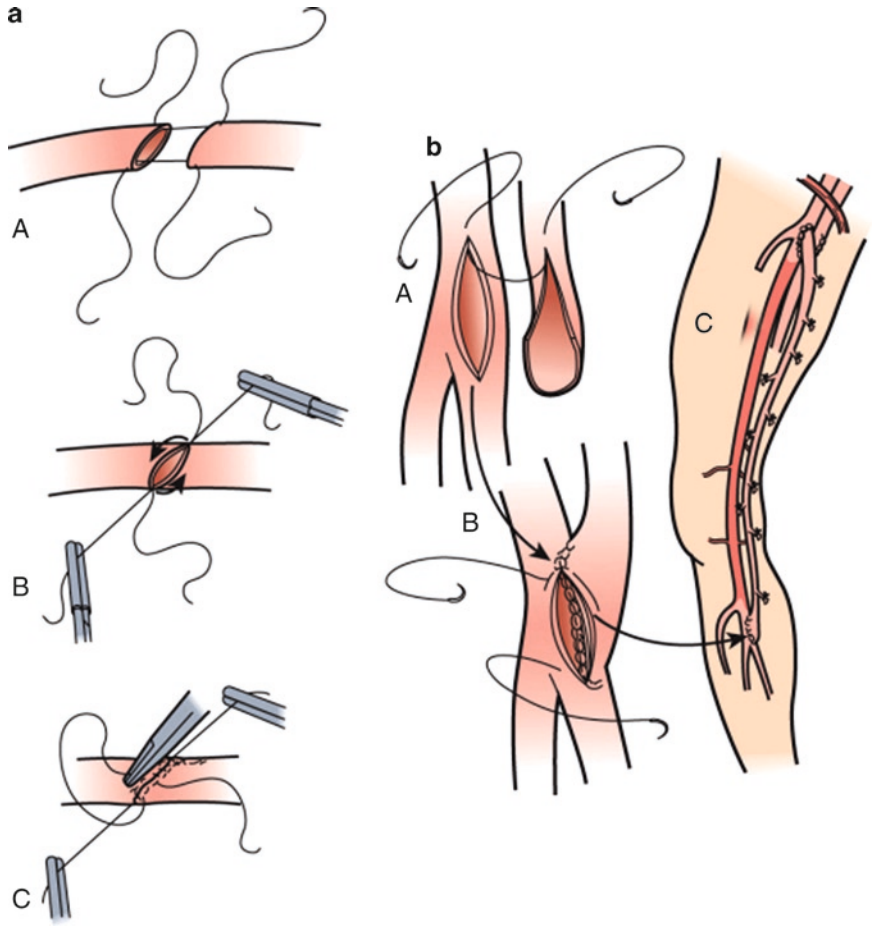

Fig. 21.4 Technique for simple vascular anastomoses. (**a**) Primary end-to-end anastomosis is performed by spatulating the vessel ends and placing opposing prolene sutures from heel to toe (A), the sutures can then be used to rotate the vessel to perform a running closure of the posterior wall (B), the other suture is then run along the anterior wall to complete the anastomosis. (**b**) Technique for end-to-side anastomosis with interposition graft begins with a longitudinal arteriotomy and matching size spatulation of the graft (A), begin the anastomosis at the heel and run the posterior (or deep) wall first (B), followed by completion of the anterior anastomosis (C). (Reprinted with permission from "Peripheral Arterial Occlusive Disease" in Sabiston Textbook of Surgery 18th edition, Townsend ed., Elsevier Publishing 2007)

clips or Bulldog clamps can also minimize the chance of a clamp injury, and should be your clamp of choice for peripheral vessels.

Upper extremity injuries should not be underestimated in their propensity to require massive transfusions from ongoing blood loss and resuscitation requirements. The arm swelling and wound expansion that can result highlights the importance of a wide tunnel for a saphenous vein graft. There has been a sustained interest in repair of venous injuries to avoid the potential for early limb loss from venous hypertension or long term disability from chronic edema. With combined injuries, arterial repair should precede venous repair to minimize further ischemic burden unless the vein repair requires very little effort.

The temporary use of shunts for military trauma is a very effective damage control technique to allow for delayed reconstruction (Fig. 21.5). The value of temporary shunting should be compared with the consequences of simple ligation. For example, ligation of the brachial artery after confirming distal signals and palmar blood flow allows for elective delayed reconstruction if indicated. Surgeons at smaller remote facilities may prefer shunting when rapid evacuation to places capable of matching transfusion requirements or performing emergent complex vascular repairs is necessary. Shunts are also an excellent option to temporarily restore blood flow if a prolonged orthopedic stabilization is required prior to definitive repair. This will also allow you to assess the distal flow with the shunt in place.

While arteriography remains the gold standard for guiding surgical reconstruction, static film arteriography has largely been replaced with portable C-arm units capable of digital subtraction angiography. Contrast arteriography is NOT required for single penetrating wounds with hard signs of a vascular injury, but is very useful for locating the injured vascular bed when there are diffuse fragmentation wounds or fractures to the extremity. Hand injected contrast images using butterfly needles without special wires or catheters can be

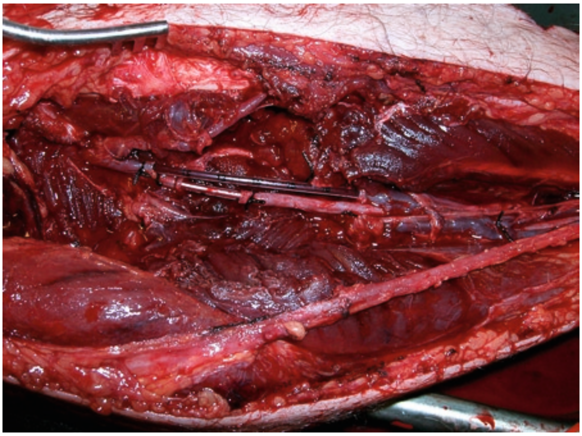

Fig. 21.5 Temporary intravascular shunts in the femoral artery and vein. These must be well secured proximally and distally to prevent dislodgment during patient transport

acquiredtquickly using the digital subtraction mode on a mobile C-arm unit. Alternatively, you can easily place a percutaneous femoral arterial line and use this to inject contrast for your study. Rotating the table before the start of the case may be necessary to properly maneuver the C-arm. When all else fails, holding the feet off the end of the table may allow for the acquisition serial images to satisfactorily complete the case. The logistics of maintaining a robust inventory in a field hospital continues to limit the capability to carry out these interventions in combat. Completion assessments following open repair or endovascular interventions make use of a combination of physical exam, the handheld Doppler, and selective arteriography.

Specific Injuries and Approaches

Femoral and Popliteal Vessels

Proximal femoral injuries are often difficult to gain proximal control, particularly if the vessel is transected and the end has retracted. Do not waste time digging in a hole or performing a laparotomy and attempting to control the external iliac deep in the pelvis. There is nothing sacrosanct about the inguinal ligament; extend your incision superiorly onto the abdominal wall, divide the musculature and inguinal ligament to enter the preperitoneal space. Gently retract the peritoneum medially to gain excellent exposure of the distal external iliac vessels.

Figure 21.6 shows the usual incisions used for lower extremity vascular exposure. Do not skimp on the incision and do not hesitate to extend wounds proximally and distally to gain adequate exposure and control. Common femoral and superficial femoral artery exposure for either an injury or to gain proximal control is relatively

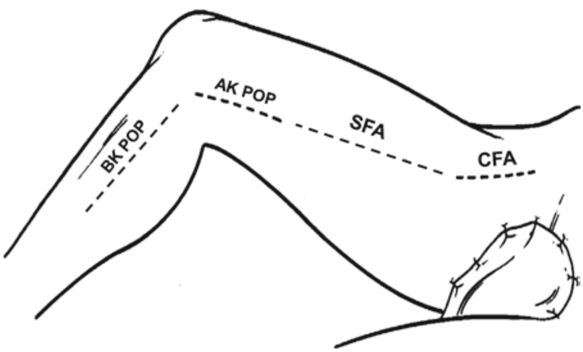

Fig. 21.6 Typical incisions for exposure of lower extremity vascular injuries. *CFA* common femoral artery, *SFA* superficial femoral artery, *AK POP* above knee popliteal, *BK POP* below knee popliteal. (Modified with permission from "Femoropopliteal Bypass Grafting" in Operative Surgery Manual 1st edition, Khatri ed., 2003 Elsevier Corporation)

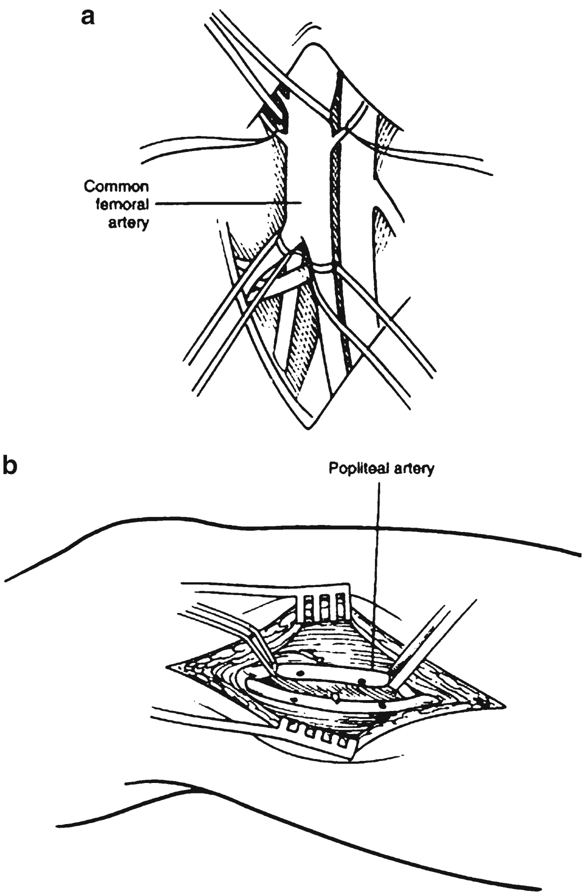

Fig. 21.7 (**a**) Exposure of the common femoral and proximal superficial femoral arteries via a longitudinal medial groin incision. (**b**) Exposure of the distal superficial femoral and above knee popliteal vessels via a medial approach. (Reproduced with permission from "Femoropopliteal Bypass Grafting" in Operative Surgery Manual 1st edition, Khatri ed., 2003 Elsevier Corporation)

straightforward as shown in Figs. 21.7a and 21.8. If needed, you can easily perform an on-table arteriogram of the entire leg from this exposure. You can also introduce an embolectomy catheter via a small arteriotomy and feed it distally to remove acute clot. You typically should not waste time trying to salvage the profunda femoris artery if injured; simply ligate it and move on.

The medial approach is preferred for femoropopliteal injuries (Figs. 21.6 and 21.7b). The approach in relation to the knee joint is directed by the level of the wound; however total division of muscular attachments at the knee is sometimes required to control hemorrhage of transected arteries and veins. Note that there will be multiple collaterals of the popliteal vein that surround the artery and will need to be divided for full exposure. An alternative approach to the popliteal

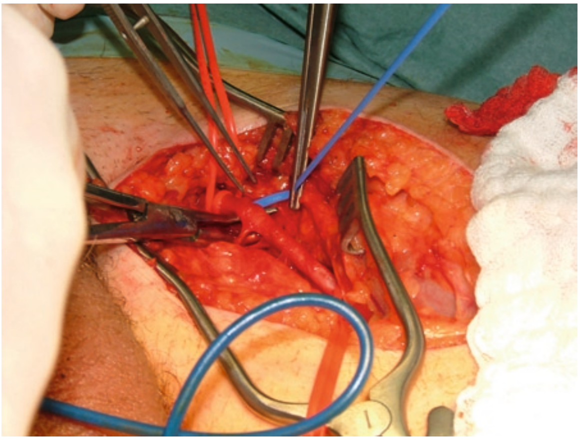

Fig. 21.8 Control of the common femoral, profunda femoris, and superficial femoral arteries in the groin

vessels is the posterior approach with the patient in prone position. Although this provides excellent exposure of the behind-knee popliteal vessels, this approach is rarely indicated for combat wounds. Saphenous vein interposition graft should be used to repair these injuries if primary repair is not feasible, particularly for repairs that cross the knee joint. If the injury is deep in the popliteal fossa, then an acceptable option is to exclude the injured popliteal artery by ligating it above and below the knee and performing a vein bypass from the distal SFA to below the distal ligation. Attempt to salvage an injured popliteal vein if at all possible, but it can be ligated if complex reconstruction would be required or in a damage control situation. Have a low threshold for performing a fasciotomy, and ALWAYS perform one if both the artery and vein have been injured.

Upper Extremity Vessels

For proximal axillo-subclavian wounds, sternotomy or left anterior thoracotomy and clamping of the subclavian artery eliminates the error of uncontrolled dissection through an expanding hematoma of the chest. You should approach distal axillary and proximal brachial arterial injuries with infraclavicular incisions and extend across the deltopectoral region into the upper arm as needed (Fig. 21.9). The course of the brachial artery and line for incision is along the medial border of the biceps muscle, with an S-shaped incision across the antecubital fossa for exposure of the brachial bifurcation (Fig. 21.10). Similar techniques as described with the lower extremity should be followed for vascular repairs. Note that kinking of a vein graft that crosses the elbow is of major concern, so examine your graft in both flexed and extended positions and tunnel it through deeper planes as needed. The other issue of particular importance with brachial artery injuries is the common association

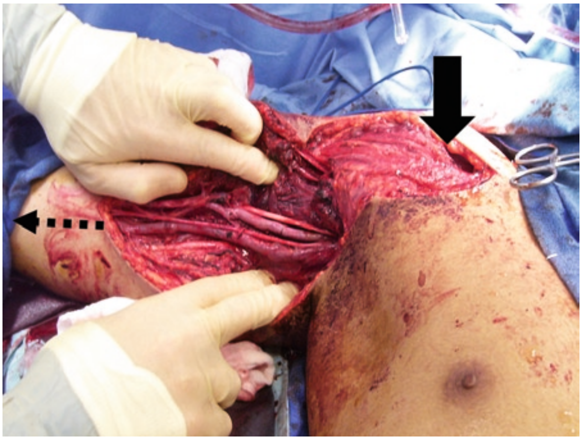

Fig. 21.9 Upper arm vascular exposure obtained with an incision starting on the chest and following the medial border of the biceps. Note full exposure of the artery, vein, and associated nerves by anterior retraction of the biceps and posterior retraction of the triceps muscles. More distal exposure obtained by distal extension to the antecubital fossa (*dotted arrow*). Control of the proximal axillary/distal subclavian vessels can be obtained by dissection through the deltopectoral groove (*large arrow*)

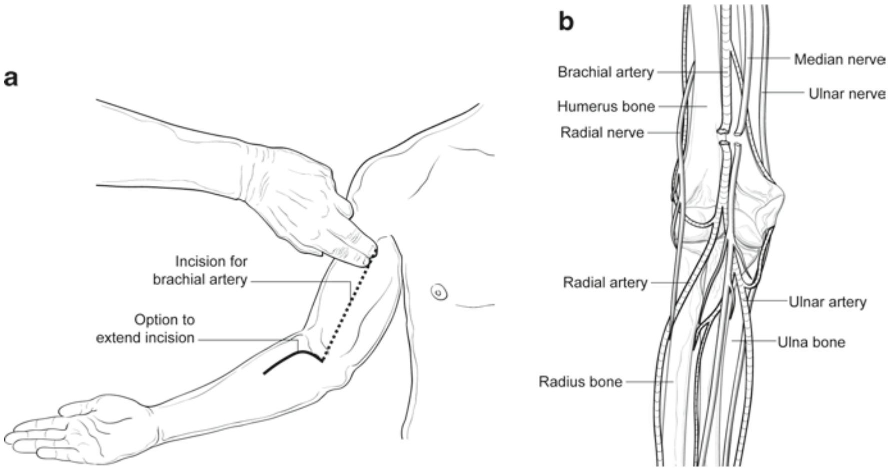

Fig. 21.10 Diagram showing distal brachial artery exposure (**a**) and relation of important nerves (**b**)

with injury to the median or ulnar nerves. Care should always be taken to do a thorough preoperative exam of hand function if possible, and to identify the nerves intraoperatively. If injured, the nerve ends should be clearly tagged for later repair (Fig. 21.11). Radial artery injuries can always be ligated as long as there is adequate flow to the hand via the ulnar artery.

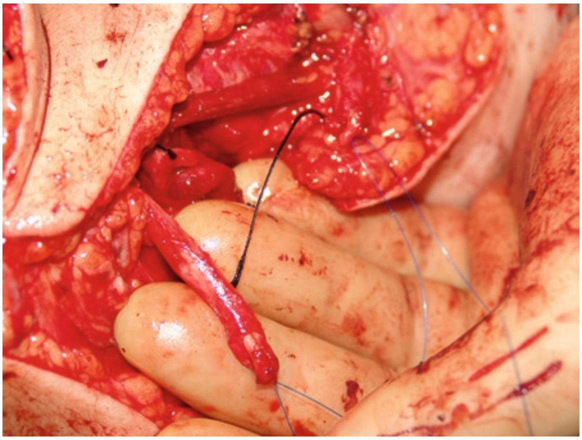

Fig. 21.11 Brachial artery injury status post repair with transection of the median and ulnar nerves. The cut ends of the nerve are identified and tagged with different colored suture for later identification (*blue* = median nerve, *black* = ulnar nerve)

Pseudoaneurysms

Although physical exam is excellent for identifying any flow-limiting peripheral vascular injury, small injuries to the vessel wall resulting in the delayed presentation of a pseudoaneurysm are not uncommon. This is particularly true for blast mechanisms with multiple soft tissue fragments; somewhat analogous to civilian shotgun wounds. Unless there is vessel thrombosis with ischemia, these are not emergencies and most should be referred to a vascular surgeon. They may require surgical repair, but often can be managed with ultrasound guided or endovascular occlusion. Distal radial artery pseudoaneurysms (from wounds or from iatrogenic injury by arterial catheterization) can be treated with simple proximal and distal artery ligation and decompression of the sac.

Postoperative Care & Evacuation

The early postoperative period is focused on patient warming, resuscitation, and hourly vascular checks that should be performed with a hand-held continuous wave Doppler probe. Palpable pulses and sometimes normal ankle-brachial ratios (>0.9) may be delayed until an appropriate resuscitation period has occurred. Patients should remain in the ICU for at least 24 h. In addition to ensuring overall cardiopulmonary and metabolic stability, plans for evacuation out of the war zone should take the threat of early graft failure and post-operative bleeding into consideration. The vascular injured patient should not be hurried unnecessarily thru the chain of evacuation. External fixators are re-adjusted based on the appearance of plain film radiographs, and a wound inspection is normally performed within 24 h. The typical patient is returned to the operating room every 48–72 h for additional washouts, debridements, and negative pressure "vacuum" dressing changes. A careful assessment for the development of a compartment syndrome is essential, especially when the patient is transferred out of the combat zone to providers unfamiliar with the initial post-operative exam. You should always maintain a low threshold for performing a fasciotomy for patients with extremity vascular injury.

Final Points

The simultaneous management of peripheral vascular injuries in the pursuit of life and limb is very challenging. The decision to amputate or reconstruct an ischemic limb requires sound judgment that often comes with experience gained on the battlefield. These patients have significant transfusion requirements and the resuscitation should not be separated from the surgery. A two team approach is an effective method that will keep speed on your side. Not all vessels have to be repaired, as brachial and tibial vessels can be ligated when a Doppler signal is obtainable in the distal limb. Systemic heparin is not necessary; however adequate intimal debridement and liberal local flushing with heparinized saline during the repair is essential. A well-covered interposed saphenous vein graft is a durable conduit and favored over prosthetic materials. Venous reconstruction should be performed when time permits. Completion arteriography is usually not necessary, but you should confirm your pulse exam with a continuous wave Doppler. Remember, your completion assessment should be continuous over the next 24 h, and if fasciotomies were not performed then you must focus on early identification of a compartment syndrome. Trust yourself, give the patient time to "catch-up", and recognize that the vascular exam will improve over time with successful repairs.

Chapter 22
The Neck

John Oh

Deployment Experience:

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Trauma Surgeon, 102nd Forward Surgical Team, Baghdad, Iraq 2007–2008

BLUF Box (Bottom Line Up Front)

1. Secure the airway early, neck injuries result in rapid compromise.
2. Neck exploration should be your default approach in the combat setting – it saves time, resources, and lives.
3. Medical illustrators are optimists, particularly in the wounded neck. Identify key structures away from the injury and work your way in.
4. You can control carotid hemorrhage with one finger – don't panic.
5. Repair carotid injuries when at all possible, or place a shunt and come back later. Ligate only as a last option.
6. Buttress the esophagus, a failed repair will take others down with it.
7. A missed esophageal injury = mediastinitis and death, therefore always drain the neck, even after a "negative" exploration.
8. Large volume bleeding from the wound after a "negative" exploration is a vertebral artery injury.
9. Median sternotomy should be your next move for large volume hemorrhage from the proximal carotid or subclavian (zone 1) area. Have the chest and groins prepped and draped.

The surgeon must have the heart of a lion, the eyes of a hawk, and the hands of a woman.

John Halle, 1529–1568

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Why Is the Neck an Important Area to Understand the Anatomy and Injury Patterns?

Major vascular and aero-digestive structures pass through the neck with little or no protection from overlying bone, muscle, or soft tissue. This means an injury to the neck can result in loss of the airway from a tracheal injury, exsanguination from injury to a major blood vessel, or sepsis from a major pharyngeal or esophageal injury. It is also an area that most general surgeons infrequently operate on, so thorough preparation is the only way to make up for the lack of familiarity in an emergent case. If you have a major neck wound I recommend bringing a surgical anatomy text or figure of the neck to the OR with you for reference.

Mechanisms and Types of Injuries to the Neck

In order to prioritize management decisions, it is helpful to elucidate the mechanism of injury to the neck. Mechanisms of injury include blunt versus penetrating, stab wounds versus missile injury, and low velocity missile versus high velocity missile injury. Stab wounds and low velocity missile injuries can cause little damage to surrounding structures in the neck in comparison to high velocity missile injuries. Shotgun injuries and blast injuries may cause multiple penetrating injuries to the neck, and identifying multiple trajectories and possible injuries require thorough work up. What you will see in combat will be much more often high velocity destructive wounds, or blast injuries with multiple small fragment wounds.

What Are the Life Threatening Neck Injuries?

Immediately life threatening injuries to the neck include injuries to major vascular structures such as the internal jugular vein or carotid artery, and injury to the trachea. The main priority with any of these injuries, whether it is a vascular injury or a direct tracheal injury, is to secure the airway and control hemorrhage. A missed esophageal injury can also be a cause of late morbidity and mortality from infection, sepsis, and possibly mediastinitis as the infections spreads from the central compartment to the mediastinum.

What Are the Injuries that Are Easy to Miss but Can Lead to Late Morbidity or Death?

In the civilian trauma literature, a selective operative management algorithm is useful, but only if you have CT angiograms or interventional radiologists available to confirm that there are not major vascular, airway, or esophageal injuries present. Clinical signs are often unreliable for ruling out major injuries that require a neck exploration. In a deployed setting, you will often not have the luxury of a CT scan or angiography. You also may not have the time or resources to carefully observe the patient and do serial exams to rule out an injury – particularly on a patient who needs to go into the evacuation chain. That means you must have a low threshold to explore the neck. A negative neck exploration has a very low morbidity rate, and mortality from a negative exploration is virtually unheard of. There are several injuries that are easy to miss but have devastating potential. Occult vascular injuries to the carotid such as a dissection or small pseudoaneurym may be asymptomatic initially but can progress to complete thrombosis or rupture. The esophagus is a notorious source of missed injuries and delayed diagnoses. Due to the lack of a serosal layer, the longitudinal muscularis may hide small mucosal perforations. Thus you should always drain the neck with closed suction drains, even after a negative exploration. A final area for potential missed injury is to the pharynx or oral cavity – remember to look in the mouth and posterior pharynx for all penetrating neck wounds.

How Should I Evaluate a Patient with a Neck Wound?

The approach to a patient with a penetrating neck wound is the same as with all other traumas. The priority is to establish a definitive airway in the unstable patient, then proceed with the remainder of the ABCs. In evaluating the trajectory of the injury to the neck, it is helpful to divide the neck into three anatomic zones. Zone I lies between the clavicles and the cricoid cartilage, zone II lies between the cricoid cartilage and the angle of the mandible, and zone III lies between the angle of the mandible and the base of the skull (see Fig. 22.1). Remember that these refer to

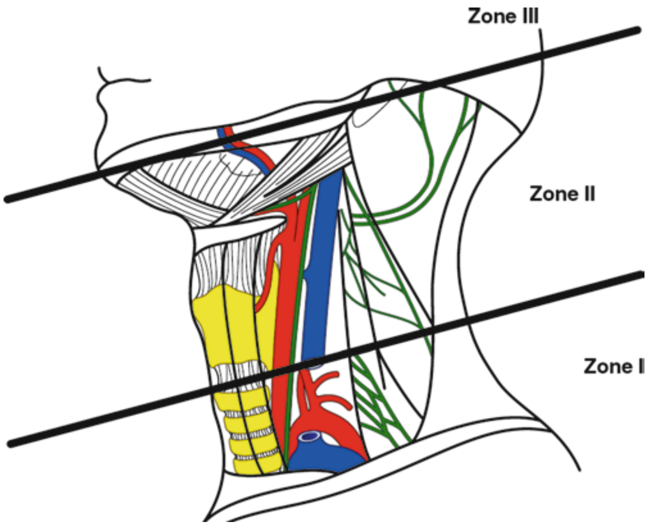

Fig. 22.1 Zones of the neck. (Reprinted with permission from Penetrating Neck Injuries, Oral Maxillofacial Surg Clin N Am 2008;20:393–414)

anterior and lateral neck wounds, and not wounds that are confined to the posterior neck or superficial wounds that have not penetrated the platysma muscle.

One of the first problems examining the neck is that someone has often placed a cervical collar, and no one wants to remove it for fear of a spinal column injury. The first maneuver you should perform is removing the collar – it is a useless obstruction to your evaluation and has almost zero chance of providing any benefit to the patient. If the spinal cord or column was hit, then the damage is done. If necessary, the collar can be replaced after your evaluation. A thorough evaluation of the neck should include observation for hematomas, pulsatile masses, bleeding or air from wounds, and tracheal deviation. Feel for crepitus, carotid pulses, and bony injuries. Auscultate for bruits and breath sounds and assess the voice for hoarseness or stridor. Examine the cranial nerves and don't forget a good intra-oral examination. Observe for any obvious hematemesis or hemoptysis. You can also have the patient spit on a gauze pad to look for any blood in the saliva suggestive of hemoptysis.

The majority of wounds to the neck lie within zone II, where the aero-digestive tract, carotid artery, vertebral artery, internal jugular vein, and cervical spine are at risk (Fig. 22.2). In addition to these structures, injuries to zone I include structures in the

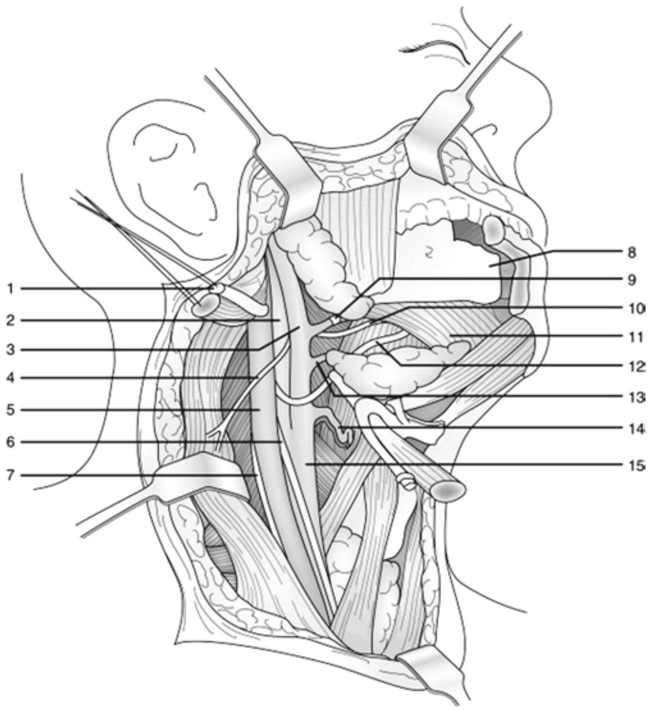

Fig. 22.2 Critical anatomy of the neck for trauma neck exploration: (1) facial nerve; (2) internal carotid artery; (3) external carotid artery; (4) spinal accessory nerve; (5) internal jugular vein; (6) vagus nerve; (7) cervical plexus; (8) mandible; (9) facial artery; (10) lingual nerve; (11) mylohyoid muscle; (12) hypoglossal nerve; (13) lingual artery; (14) superior thyroid artery; (15) common carotid artery. (Reprinted with permission from Penetrating Neck Injuries, Oral Maxillofacial Surg Clin N Am 2008;20:393–414)

thoracic inlet, such as the aortic arch, proximal carotid, and subclavian vessels. Injuries to zone III also include the cranial vault and pharynx. In an unstable patient with penetrating trauma to the neck, you should proceed directly to the operating room. The presence of "hard signs" of injury such as obvious uncontrolled hemorrhage, expanding or pulsatile hematomas, "sucking" neck wounds, unexplained hypotension or lateralizing neurologic signs should also prompt immediate surgical exploration. If you have a hole in the neck and hard signs of a vascular injury, you do not need a CT scan to confirm the injury or to tell you where it is. You need to be in the OR for a neck exploration and prepared to do a sternotomy or clavicular extension.

In the civilian literature, zone I and III injuries are often first evaluated by a combination of CT scan, bronchoscopy, esophagoscopy, esophagogram, and angiography. Zone II injuries are typically explored in the operating room if they present with classic "hard signs." Otherwise, they are managed non-operatively with imaging and close serial examination. In austere settings where thorough, non-operative evaluation is not possible, penetrating injuries to any of these zones requires surgical exploration. In these cases, you will do some negative or non-therapeutic explorations, but you will find significant injuries much more commonly than is reported with civilian type mechanisms. However, due to the low morbidity and mortality of a negative exploration, this is acceptable. It is far more devastating to have a missed injury or delayed therapy. All high velocity wounds and bilateral neck wounds should prompt exploration.

An exception to this is the blast victim who has multiple tiny fragment wounds (typically >10) involving the neck. These could have caused significant injuries to any neck structure, or they may just be superficial scratches. If the patient has a normal neck examination as outlined above and is hemodynamically stable, then you should obtain a CT arteriogram of the neck. This should identify the vast majority of major neck injuries, and also identify the location of any retained fragments. If the exam and the CT scan are normal then the patient can be safely observed. If there is any concern for an esophageal injury, then you can add a swallow study and/or endoscopy to your evaluation. Watch this patient for at least 24 h to ensure stability and no delayed manifestation of an occult injury.

Techniques of Exposure, Exploration and Repair of the Common Injuries

Vascular Injuries: Common, Internal, and External Carotid Arteries, Jugular Vein

The general approach to a penetrating neck injury is to prep and drape from the base of the skull to the knees. Shave the groin and thighs for possible saphenous vein harvest. In addition, take the time to position your patient properly. This includes a shoulder roll underneath the shoulderblades to help extend the neck. If you have unilateral injury, turn the head slightly away from you and use a head support.

Keep in mind that cervical collars are unnecessary for isolated, penetrating neck traumas. If there is a neurologic injury from penetrating trauma, the neurologic deficit does not progress with manipulation of the neck, unlike a blunt force cervical spine fracture. Proper positioning will greatly enhance the operative exposure of the neck.

There are multiple incisions and extensions that can be used in the neck (Fig. 22.3). For trauma exploration, the basic incision for penetrating neck trauma is along the anterior border of the sternocleidomastoid muscle (SCM), just as you would for a carotid endarterectomy. The incision should extent from the mastoid process to the sternal notch. This incision will allow access to the major vascular and aerodigestive structures of the neck. Exposure of the esophagus is best gained via the left neck, but can be obtained from either side. You should always be prepared to extend your incision inferiorly into a median sternotomy for proximal vascular control, or to "hockey-stick" the inferior end transversely across the clavicle to expose the subclavian vessels. Do not hesitate to resect a portion of the clavicle or disarticulate it from the manubrium to gain full exposure of the subclavian vessels. Finally, for bilateral neck explorations you can either make mirror image standard incisions or make a collar incision with bilateral superior extensions along the SCM.

The first landmark you must look for after dividing the platysma muscle is the anterior border of the SCM. Retract the SCM laterally, and maintain your dissection along this plane. If you are in the correct plane, the dissection will proceed easily with proper traction and counter-traction. If you encounter longitudinal muscle fibers, your dissection is too lateral. Move anteriorly until you find the anterior muscle border (Fig. 22.2).

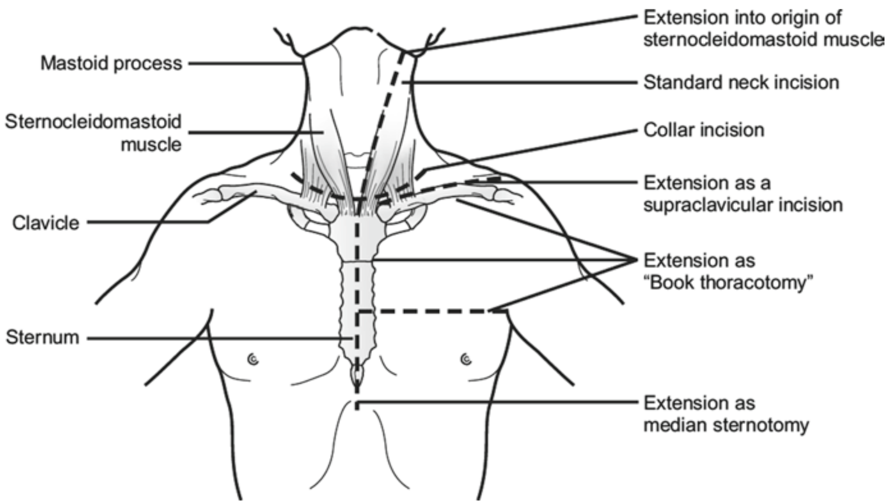

Fig. 22.3 Incisions for standard trauma neck exploration and optional extensions for zone I and zone III vascular control. (Reprinted with permission from Penetrating Neck Injuries, Oral Maxillofacial Surg Clin N Am 2008;20:393–414)

This will lead you directly into the fascia of the middle cervical space. As you open this fascial layer, the first vessel you encounter is the internal jugular vein (IJ). This is the most commonly injured vessel in the neck. If the injury to the IJ is obvious and repair is straightforward, proceed with primary repair using a 5-0 Prolene suture. Otherwise, you should not hesitate to ligate the vein and move on to identifying more significant injuries. The next landmark to look for is the facial vein – this is the gateway to the carotid exposure and locates your carotid bifurcation. Ligate and divide the facial vein in order to facilitate exposure and gain control of the carotid artery. As you mobilize the vein laterally, the carotid artery will be medial and posterior. The carotid bifurcation will be immediately below the facial vein, with the external carotid immediately diving medially into the deep neck and face area, and the internal carotid coursing superiorly (Fig. 22.4). Nerves to watch out for in this area are the vagus nerve, which runs on the posterior surface of the carotid artery, and the hypoglossal nerve running transversely across the internal carotid just below the ramus of the mandible (Fig. 22.2). Beware of direct injury to this nerve or traction injury from superior wound retraction.

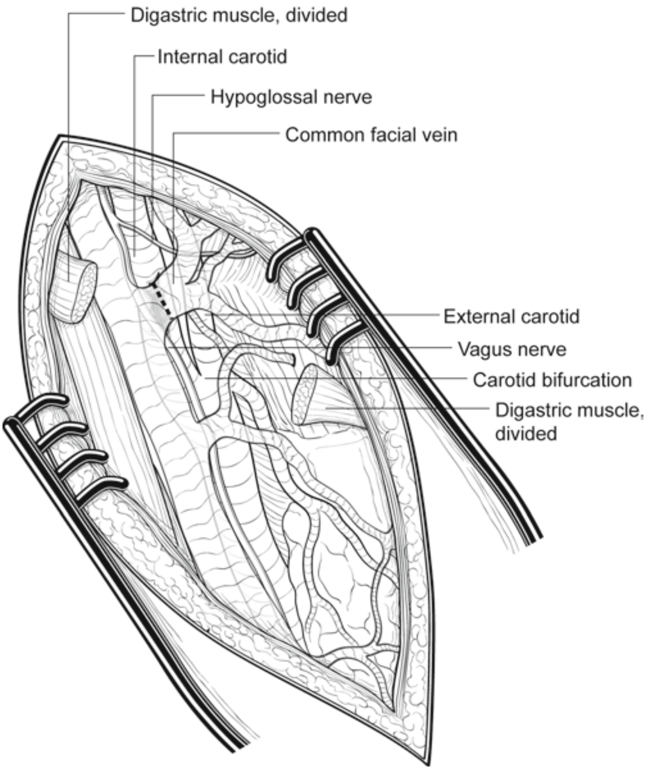

Fig. 22.4 Exposure of the right carotid artery and carotid bifurcation by ligation of the facial vein and retraction of the internal jugular vein laterally

The first decision that you need to make after exposing the carotid artery is to repair or ligate. Unilateral *external* carotid artery ligation may be performed without significant sequelae. However, ligation of the common or internal carotid artery can result in devastating cerebral ischemia. Therefore, ligation of these vessels should only be performed in extreme circumstances such as uncontrolled hemorrhage, devastating injuries where repair is not possible, or in cases where the patient presents in frank coma. In all other cases, repairing the artery results in improved outcomes and should be attempted. The concern over repairing an "occluded" artery that may subsequently shower emboli or cause intracranial hemorrhage with a worsening neurologic deficit appears to be theoretical. Accumulating evidence shows that these patients do better with repair. If you don't have the equipment, time, or expertise to repair the vessel then your next choice should be placing a shunt rather than ligating (see below).

Use the principal of proximal and distal control when exposing the injured carotid artery. Obtain proximal control first outside of the hematoma in an injured artery. This may require a median sternotomy to gain adequate control. Place a Rummel tourniquet and proceed with the dissection along the carotid artery. Stay in the peri-adventitial plane, this will prevent inadvertent injury to adjacent structures, such as the vagus nerve that lies within the carotid sheath running parallel to the artery. Also remember that the hypoglossal nerve overlies the internal carotid artery just after the bifurcation. During your dissection, try to avoid cutting structures you encounter. A safer strategy is to bluntly push the adjacent structures aside.

Next, obtain distal control in virgin territory outside of the hematoma if possible. You will often find that the hematoma extends to the mastoid process. In this case, you need to enter the hematoma directly. Be prepared to encounter back bleeding from the internal and external carotid arteries as you expose the injury. In order to rapidly gain hemostasis, use direct pressure with your finger first, then gain distal control with a Rummel tourniquet or vascular clamp. If those maneuvers fail, inflate a No. 3 Fogarty catheter into the lumen of the vessel with a three way stopcock attached to the end. When inserting a Fogarty catheter into the internal carotid artery, take care not to rupture the carotid siphon. This means advancing the Fogarty no more than 2–3 cm beyond the bifurcation. Once you gain control of the common, internal, and external carotid artery, you have achieved complete vascular control (Fig. 22.5).

If you find that the injury to the internal carotid artery extends into zone III, you have few repair options available. First, divide the posterior belly of the digastric muscle to improve exposure of the distal carotid artery. You can gain an additional 2–3 cm of exposure by anterior subluxation and fixation of the mandible (Fig. 22.6). If you have an ENT or OMFS colleague available they can be of great assistance with this. If you encounter vigorous back bleeding and are unable to obtain distal control, the only real option is to attempt to ligate the distal artery if you can gain purchase of it. Otherwise, inflate a Fogarty balloon within the lumen, place vascular clips on the balloon catheter, and cut the distal end. This will end up being your definitive repair. Not the most elegant solution, but it will work in a pinch.

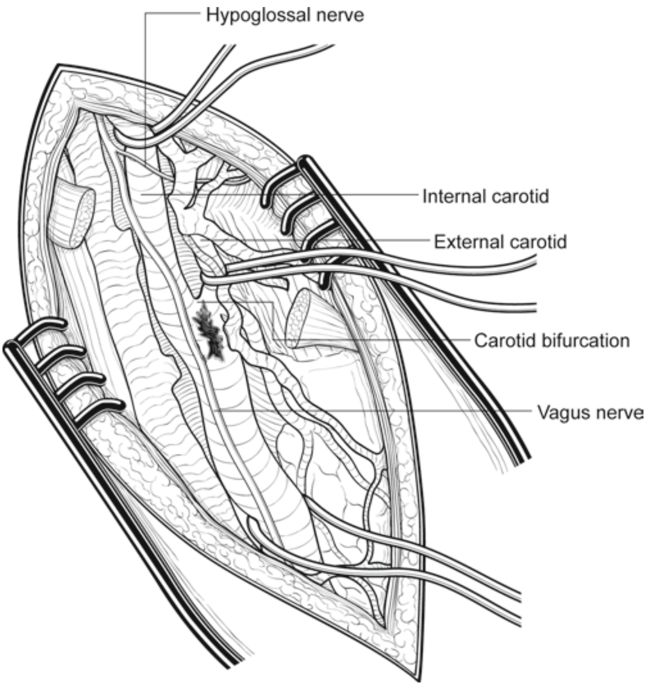

Fig. 22.5 Vascular control of the carotid artery

Definitive repair of the carotid artery can be performed primarily with interrupted 5.0 prolene suture if the injury is a simple laceration – rarely seen in combat injuries. Otherwise, you may use a patch or interposition graft. In general, a prosthetic graft should be used for the common carotid artery (Fig. 22.7) and a reversed saphenous (or other site of appropriate size) vein graft for the internal carotid artery. The necessary steps are to debride to healthy, uninjured intima proximal and distal to the injury. Next, perform a catheter embolectomy proximally and distally with a No. 3 Fogarty catheter, and flush the ends with heparinized saline. If you need to place an interposition graft, perform the distal anastomosis first, applying the posterior row of sutures first, working anteriorly. When you get to the last several sutures of the repair, open the external carotid to allow back-bleeding to flush out any clot. Then complete the repair and open the common and external carotids to allow any remaining clot to be flushed into the external system. Open the internal carotid to antegrade flow last. Another repair option for a proximal internal carotid artery injury is to divide the external carotid artery and transpose the proximal end to the internal carotid artery distal to the injury (Fig. 22.8). Confirm flow using a sterile Doppler flow probe, if available.

What if your patient has multiple injuries, or needs a damage control operation due to physiologic deterioration? One option is to ligate the carotid artery, as mentioned previously. Another damage control option is to place a shunt while you address the

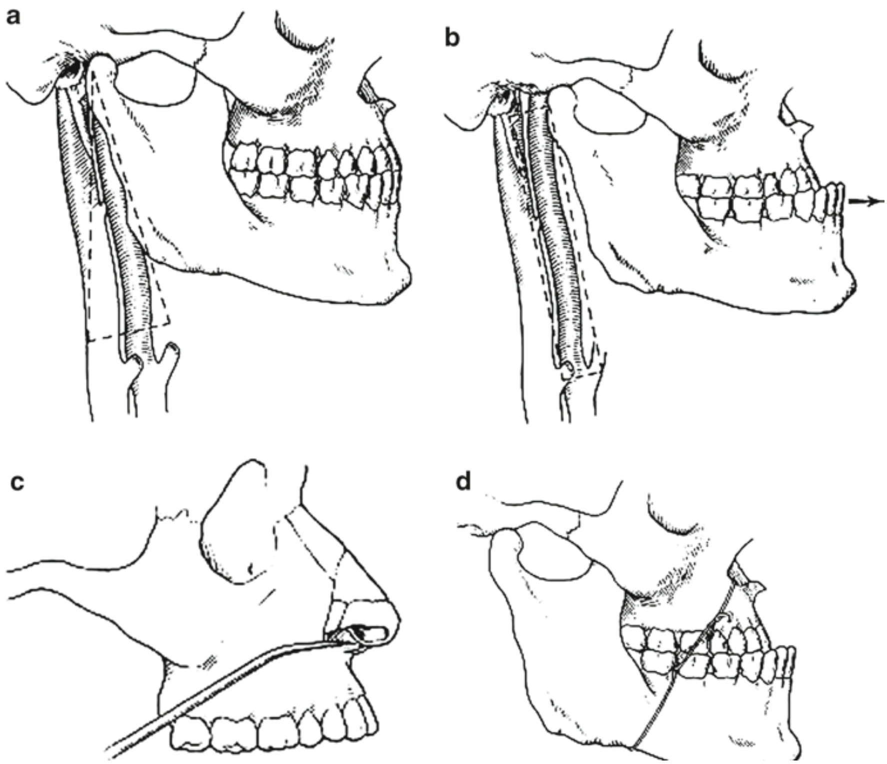

Fig. 22.6 The distal internal carotid artery exposure is hindered by the manibular ramus, creating a triangular space with a narrow apex (**a**). Forceful anterior traction on the mandible will convert this to a rectangular space providing several centimeters of additional distal exposure (**b**). The mandible can be maintained in this position by manual retraction or placement of trans-nasal fixation wires (**c** and **d**). (Reprinted with permission from Neck Injuries, Current Problems in Surgery 2007;44:1–73)

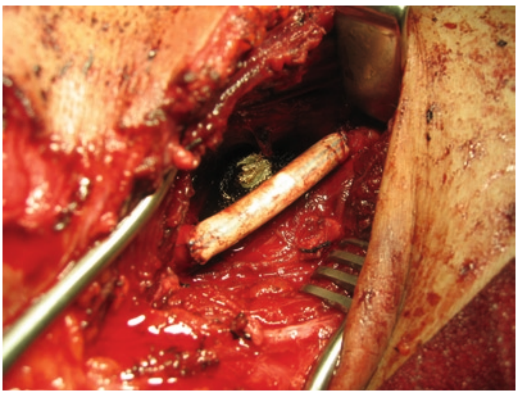

Fig. 22.7 Prosthetic interposition graft (PTFE) of the common carotid injury for a large fragment wound to the neck

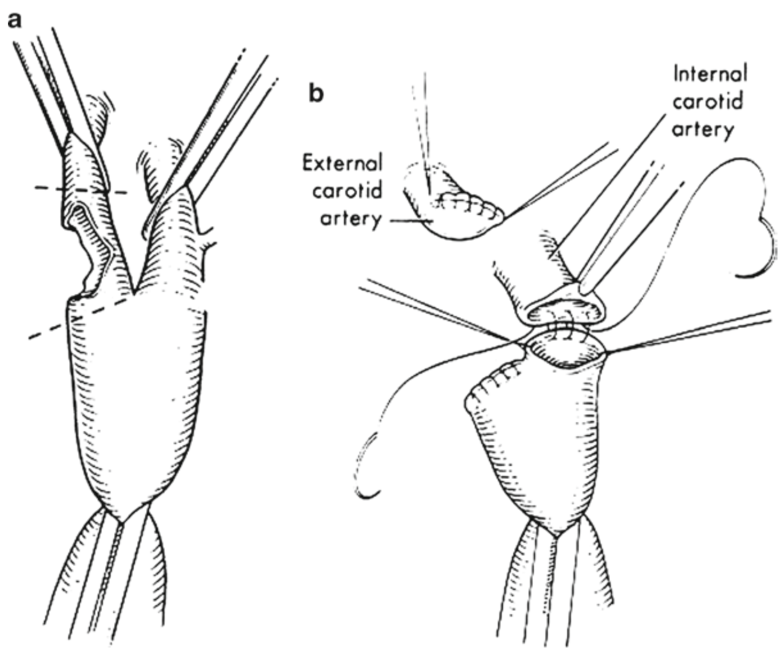

Fig. 22.8 External to internal carotid artery transposition procedure. (**a**) Injury to the proximal internal carotid artery is excised. (**b**) The external carotid artery is divided and the proximal end is anastomosed to the distal end of the internal carotid artery, re-establishing cerebral perfusion. (Reprinted with permission from Neck Injuries, Current Problems in Surgery 2007;44:1–73)

other injuries or complete your resuscitation in the ICU. You can always return to the OR for definitive repair later. There are various sets of carotid shunts that are specifically designed and sized for use in the common and internal carotid arteries. If you do not have these available, you can use a pediatric feeding tube or nasogastric tube cut to proper length and flushed with heparin solution. Make sure to secure the shunt in place with silk ties around the proximal and distal vessel ends – preferably in the damaged areas or as close to the damaged ends as possible to preserve vessel length.

Esophagus

Within the neck, the esophagus lies deep to the carotid sheath, anterior to the cervical spine, and posterior to the trachea slightly left of midline. Place a naso-gastric tube to help you palpate the esophagus. You can approach the esophagus by retracting the carotid sheath laterally (the anterior approach). This may be the easier approach if you have already explored the vessels in the carotid sheath.

An alternative approach is to move the carotid sheath medially, and approach the esophagus posteriorly. This may be the preferred approach if you have not entered the carotid sheath, or if you are attempting to stay out of a large hematoma in the carotid sheath You will find, however, that the anterior approach provides better exposure of the cervical esophagus. To fully expose the esophagus, you will need to divide the omohyoid, middle thyroid vein, and inferior thyroid artery (Fig. 22.9). Do not bother to take time looking for the recurrent laryngeal nerve as it will often be obscured, but avoid dividing any longitudinal structures in the tracheo-esophageal groove. Once you have your planes identified you can use blunt finger dissection or a large angled clamp to encircle the esophagus. Placement of an umbilical tape or penrose drain above and below the injured area allows retraction of the injury into your operative field.

Whatever route you choose in your approach, understand that the esophagus easily contains "hidden" injuries. Due to the lack of a serosa, injuries are more difficult to identify, and the extent of mucosal injury is often greater than the injury to the muscular layers. Consider this when debriding devitalized tissue in an esophageal injury. Another option, if available, is to perform an intra-operative esophagoscopy to identify occult mucosal injuries. Otherwise, you can ask the anesthesia provider to pull back the naso-gastric tube and insufflate the esophagus with air as you instill saline into the wound, looking for an air leak.

Once you have identified the injury, use conservative debridement to healthy tissue. Remember that the internal mucosal injury is often longer than the external muscular layer injury. Extend the muscular defect to identify the edges of mucosa, which can then be elevated into the wound and repaired (Fig. 22.10). If the injury is amenable to primary repair, use an absorbable monofilament suture. You can use a one or two layer technique, ensuring that there is no tension on the repair. Alternatively, use a linear stapler on the mucosa and then suture repair of the muscular layer (Fig. 22.10). Once your suture line is complete, buttress it with a piece of healthy, vascularized tissue by mobilizing the strap muscles, omohyoid or SCM. These structures can be easily mobilized from their attachment to the sternum. Buttressing your repair is especially important if you have to repair another injured structure in the neck, such as the carotid vessels or the trachea.

If the injury cannot be repaired primarily, the best option is to create a controlled fistula by performing a lateral esophagostomy (Fig. 22.11), or by placing a drain and exteriorizing it. If you can, place a large closed suction drain into the lumen of the esophagus through the injury and purse string around it. If you have a high injury in the hypophayrnx, simply place an exteriorized drain adjacent to the suspected injury. These injuries will often close on their own with appropriate drain management. If you have an unstable patient with multiple injuries and a destructive injury to the cervical esophagus, simpler and faster is better. You can exclude the injured area rapidly with a TA stapler fired above and below, or use umbilical tapes to ligate the esophagus above and below the injury.

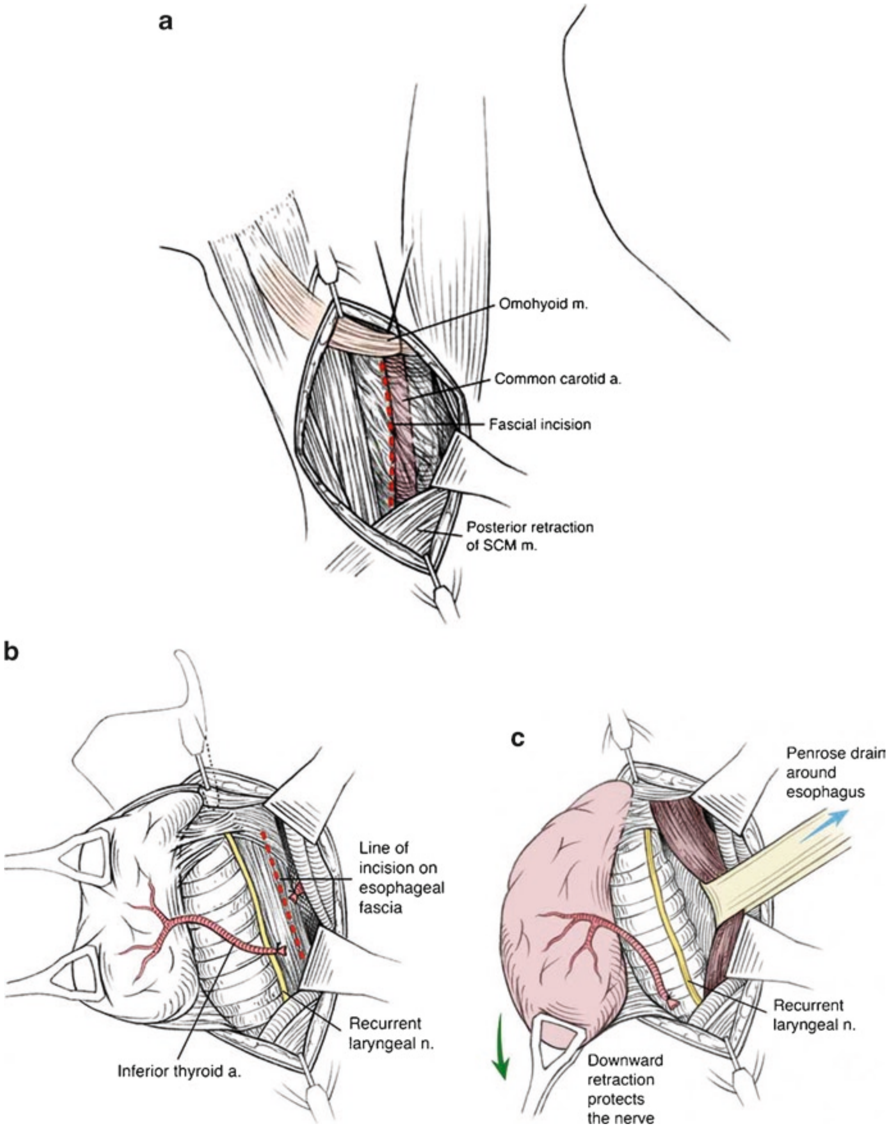

Fig. 22.9 Exposure of cervical esophagus. (**a**) Incision of superficial fascia along anterior border of sternocleidomastoid; (**b**) Incision of deep investing fascia over the esophagus, posterior to the recurrent laryngeal nerve; (**c**) Circumferential mobilization of the esophagus. (Copyright 2009. Reproduced by permission of CTSNet, Inc. All rights reserved)

What if you suspect an injury to the contralateral side of the esophagus? One tactic is to make a contralateral incision in the neck. Another, more difficult option is to attempt to fully mobilize the esophagus. This is not recommended unless you have experience with esophageal surgery. With mobilization, there is a high risk of iatrogenic

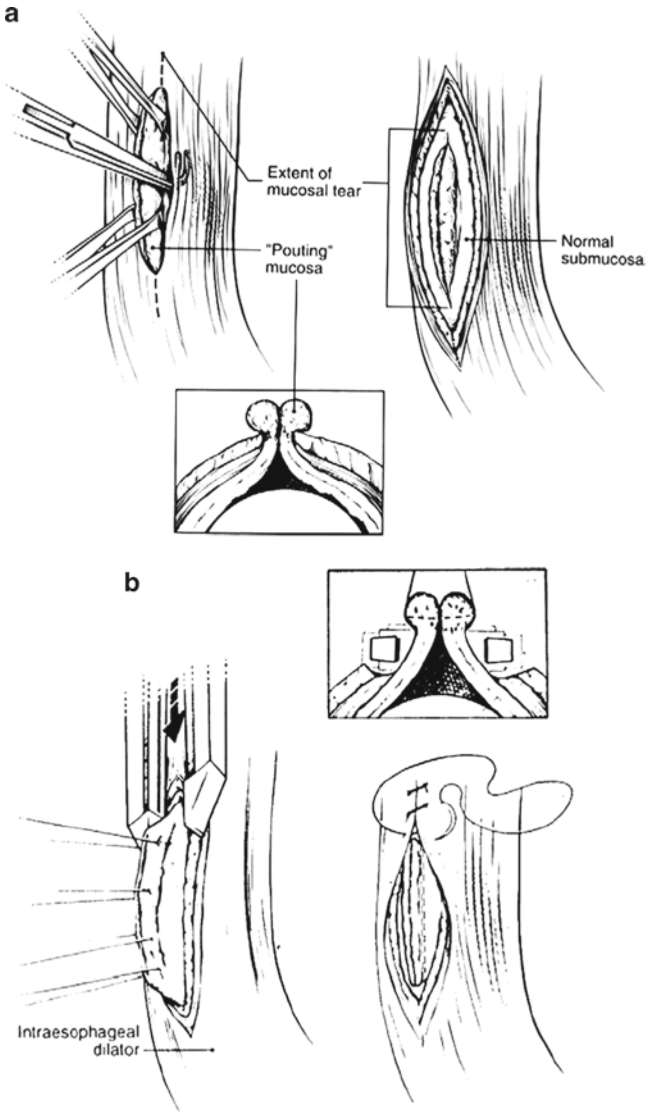

Fig. 22.10 Stapled repair of an esophageal injury. (**a**) Extend the muscular defect proximally and distally to expose the extent of the mucosal injury. Grasp and elevate the mucosa into the defect using forceps or stay sutures. (**b**) A linear stapler is used to close the mucosal defect, and the muscular layer is approximated with interrupted or running suture. (Reprinted with permission from Intrathoracic esophageal perforation: the merit of primary repair. J Thorac Cardivasc Surg 1995;109:140–146)

injury to the esophagus, recurrent laryngeal nerve, and trachea. An alternative option is to simply place an exteriorized drain until more definitive repair can be accomplished. An air insufflation test can help with this decision – if you have a small leak, leave a drain and get out. If you have a large air leak, explore and repair/drain the other side.

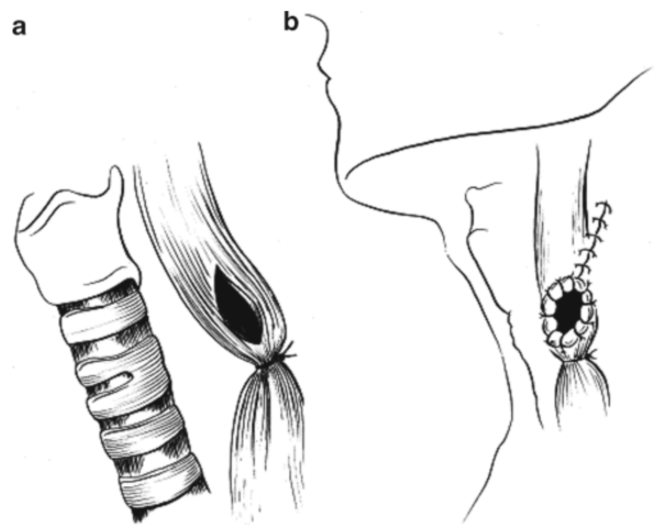

Fig. 22.11 Creation of a cervical esophagostomy. (**a**) Ligate the distal esophagus and make a longitudinal esophagotomy in the most mobile portion (or use the injury itself). (**b**) Mature the esophagostomy into the inferior part of the incision with interrupted sutures to the skin. (Reprinted with permission from Complete esophageal diversion: a simplified and easily reversible technique. JACS 2004;199:991–993)

Trachea

The simplest thing to do with an anterior injury to the tracheal wall is to insert an appropriate size tube and convert it to a tracheostomy. Otherwise, simple lacerations to the trachea may be repaired primarily with an absorbable, mono-filament suture with the knot tied on the outside. It is important to create a completely tension free repair. If you have a large defect with significant loss of cartilage, you may attempt to mobilize the trachea and perform a primary anastomosis. However, I would only recommend this if you are experienced with tracheal surgery. Otherwise, use one of following damage control options:

1. Place a oral or naso-tracheal tube with the balloon inflated past the injury.
2. Intubate directly through the injury itself.

These damage control options will allow you to transfer the patient to definitive care.

Vertebral Arteries

This can be one of the most frustrating injuries encountered in the neck. This is because the vessel is deep and posterior in the neck, and is encased in the transverse

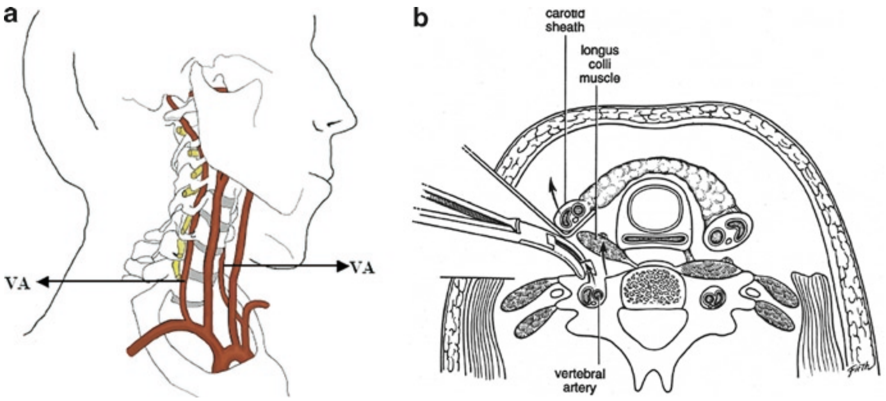

Fig. 22.12 Management of vertebral artery injuries. (**a**) Vertebral arteries ascend in the neck within the vertebral foramina of the cervical spine; (**b**) posterior approach to the vertebral artery and exposure using rongeur to remove the surrounding bone and open the vertebral foramen. (Reprinted with permission from Neck Injuries, Current Problems in Surgery 2007;44:1–73)

process of the cervical vertebrae (Fig. 22.12a). Upon exploration of the neck, what you will find is an intact carotid sheath with blood spurting from the paravertebral muscles posteriorly. Mobilize these muscles laterally with a periosteal elevator to expose the transverse processes. You can guide your exposure by palpating the transverse processes (Fig. 22.12b). Exposure of the vertebral artery is difficult at best, and the preferred management of a vertebral artery injury in civilian trauma centers is angiography and embolization. You will likely not have this luxury. You may be able to clip the vessel ends if visible between the cervical vertebrae, but if not then use a rongeur to remove the lateral portion of the transverse process and expose the vessel. An alternative simple solution is to plug the hole with bone wax. Hemostatic dressings such as QuikClot have also been used with excellent results. This will work for most small injuries. If you still have bleeding, identify the vessel at the base of the neck as it comes off the subclavian artery. It is not encased in bone at this point and is relatively easy to expose and ligate. You may still get some backbleeding from the distal end; place a balloon catheter into the lumen of the vessel distally.

Final Thoughts

Management of the combat neck wound will often take you out of your usual comfort zone, so run through the anatomy and scenarios in your head to prepare for the real thing. Focus on the two major immediate threats to life – bleeding and hemorrhage; everything else can wait and be approached in a more thorough manner. Get help – you cannot perform exposure and dissection in this area on your own and a second pair of trained hands and eyes is invaluable. Have a low threshold for performing a neck exploration, and a high threshold for attempting nonoperative management. Before you transfer your patient to another facility or place them in the evacuation chain, you should either have definitively addressed their major neck injuries or have assured yourself that there is no significant injury. Remember that speed and simplicity are critical factors in combat trauma surgery, and will lead you to success in the "high value" territory of the neck.

Chapter 23
Genitourinary Injuries (Excluding Kidney)

Andrew C. Peterson

Deployment Experience:

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10th Combat Support Hospital, Baghdad, Iraq, 2005–2006

BLUF Box (Bottom Line Up Front)

1. Most general surgeons will not be deployed in conjunction with a urologist; *they* must be the urologist.
2. In the combat setting there is no reliable method to establish whether the testicular or scrotal contents are involved in penetrating or blunt trauma and therefore prompt surgical exploration is recommended.
3. In settings of complicated genitourinary trauma (e.g., if you think bilateral orchiectomy may be required), consider damage control maneuvers and evacuation to the in-theater urologist.
4. Early surgical exploration of penetrating trauma to the penis with complete repair of the urethra and corporal bodies leads to a significantly better long term outcome.
5. Contraindications to placement of the Foley catheter without imaging include blood at the urethral meatus, a high riding prostate on physical examination, perineal or penile hematoma, and any suspicion of a urethral injury.
6. Consider full lower genitourinary tract imaging with retrograde urethrogram followed by catheter placement and cystogram in all cases with suspected urethral injury.
7. The indicators of bladder injury in both blunt and penetrating trauma include: gross or microscopic hematuria, concomitant perineal or genitourinary trauma, pelvic fracture, abdominal distension, suprapubic pain, and free fluid on abdominal CT or FAST.
8. Operative exploration of bladder injuries requires opening the dome of the bladder with careful inspection from the inside.
9. Suprapubic catheters are NOT required for most bladder injuries. Repair and then drain from the inside (foley) and outside (JP drain).

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The testicle having been thus cleared is to be gently returned through the incision along with the veins and arteries and its cord; and it must be seen that blood does not drop down into the scrotum, or a clot remain anywhere.

Celsus, 25 BC–AD 50

What Genitourinary Injuries will I have to Deal with in Combat?

You get called to the ER tent for an "abdominal gunshot wound" and begin planning your laparotomy during the walk. When you arrive, you discover that the wound is actually a degloving of the pubic area with a large laceration and partial scrotal avulsion. Suddenly you are not so confident about what to do next. Many general surgeons will be deployed for extended periods of time without the assistance of a urologic surgeon. This chapter addresses the basic evaluation and management of lower genitourinary trauma for the surgeon when no urologist is available.

Although uncommon in civilian injuries, genital trauma occurs in up to 60% of patients injured on the battlefield. The current reports from the conflicts in Iraq and Afghanistan are consistent with historical experience from Viet Nam, Korea and World War II. Explosion injuries can account for up to 75% of the lower urinary tract injuries. While isolated injuries to the genitourinary system and perineum may occur, it is exceedingly important to remember that these injuries often accompany trauma to multiple other organ systems. Therefore, stabilization of the patient with initial resuscitation is paramount as the majority of the external genitalia injuries can be safely managed initially with simple debridement, urinary diversion and local wound care.

When evaluating the patient with genitourinary trauma, consider the mechanism of injury and the weapon used. Genitourinary trauma can be classified as blunt (for example from flying debris from explosives), low velocity penetrating injuries (fragments from explosive devices), high velocity gunshot wounds, avulsions, burns, and crush injuries. The majority of injuries to the perineum and scrotum are most likely to arise from improvised explosive devices (IED), oftentimes presenting the surgeon with devastating injuries to the perineum, scrotum, and urethra which require urinary diversion and wound debridement. Some of these are accompanied by fecal contamination, thus requiring fecal diversion as well (see later). The treatment principles are the same for the entire perineum, scrotum, and penis. These include immediate exploration for penetrating injuries, copious irrigation, excision of all foreign matter, antibiotic prophylaxis, and surgical closure.

What Do I Need to Assess in a Patient with Scrotal or Penile Wound?

While the obvious injuries in these cases are at the skin level with significant maceration, burn wounds, and traumatic avulsion of skin of the perineum, scrotum, and penis, it is imperative to appreciate the possible involvement of surrounding

Fig. 23.1 Most trauma to the perineum and genitalia in the current conflict will consist of a mixture of penetrating, blunt and avulsion injuries from improvised explosive devices

structures (Fig. 23.1). Always completely evaluate the urethra, bladder, and corporal bodies. When not detected, injuries to the corporal body may result in prolonged bleeding and possible future erectile dysfunction. Likewise, untreated urethral and bladder injuries may result in prolonged urinary leak with extravasation of possibly infected urine causing urinoma, abscess, and sloughing along with infection of the perineum, penis, and scrotum. These can be devastating complications! Therefore, the retrograde urethrogram and cystogram should be used liberally in all patients with any injury to the penis, scrotum and perineum. They should also be used in any patient with blood at the meatus or any difficulty with urination when there are penetrating or blunt injuries anywhere near the urethra and lower abdomen.

How Can I Best Diagnose a Bladder or Urethral Injury?

Initial evaluation for trauma to the lower genitourinary tract depends upon the presence or absence of hematuria (gross or microscopic) and the mechanism and location of the injury. In all cases perform a careful genitourinary examination including diligent palpation of the penis, scrotum, abdomen, and perineum with a digital rectal examination in order to evaluate for the location of the prostate as well as to palpate any fragments or foreign bodies. Complete radiographic evaluation is necessary when there is blood at the meatus on presentation, gross hematuria, penetrating trauma to the lower abdomen or perineum, and in pediatric patients. Obtain imaging in patients with microscopic hematuria (less than 180 red blood cells per high-power field or blood that is not visible in the urine) who have accompanying shock with any mechanism of injury. In the absence of hematuria, if the mechanism of injury is concerning for a genitourinary injury (pelvic fractures or blunt trauma to the lower abdomen, penis or scrotum, and perineum), a complete radiographic evaluation should be performed. Think of the evaluation in this region as starting with the tip of the penis moving proximally to the bladder. When imaging is indicated, start with the retrograde urethrogram, then place a urethral catheter and proceed with the cystogram (see later for details on how to perform these studies). An algorithm outlines the complete evaluation and management for lower genitourinary tract trauma in Fig. 23.2.

Contraindications to placement of a Foley catheter without imaging in the face of lower genitourinary trauma include blood at the urethral meatus, a high riding prostate (indicating distraction of the urethra from the membranous urethra), perineal hematoma, or the suspicion of a urethral injury such as the presence of a butterfly hematoma, scrotal hematoma, or penetrating penile injury. If you do not have imaging capabilities, you may attempt to gently pass a small Foley catheter into the bladder. This will often be successful with partial urethral injuries and will serve as an initial stent until the injury can be further evaluated by a specialist. Stop any attempt at passage if you meet resistance or do not get return of urine.

Management for the General Surgeon

Penis

External injuries to the penis may include damage to the corporal bodies and the urethra in up to 50% of the cases despite the absence of blood at the meatus on presentation. Early surgical exploration is indicated to repair injuries to the urethra and corporal bodies and gives a significantly better long term outcome with respect to erectile dysfunction and voiding. Use of the retrograde urethrogram is imperative prior to exploration in order to plan the surgical approach and repair.

The best way to expose the penis for penetrating or blunt injuries is through a circumcision incision. The shaft skin may be degloved from the penis and the corporal bodies and urethra directly inspected. On exploration significant hemorrhage can be controlled initially with direct compression and gauze sponges. Should bleeding be extremely brisk, control may be easily obtained through the use of a tourniquet at the base of the penis consisting of a Penrose drain held in place with a Kelley clamp. Any lacerations or injuries to the corporal bodies are closed with interrupted 2-0 Vicryl for a watertight closure. In the uncircumcised patient a completion circumcision will usually be required to avoid phimosis and paraphimosis from the postoperative edema.

Traumatic amputation of the penis is rare but may result from explosion injuries or even self-mutilation. While reconstruction of the urethra with anastomosis of the corporal bodies and microsurgical repair of penile vessels can achieve remarkably good results, these are rarely indicated nor often possible in a deployed environment. In these cases the penile stump should be formalized by closing the corporal bodies in a watertight fashion to prevent bleeding, spatulation of the end of the

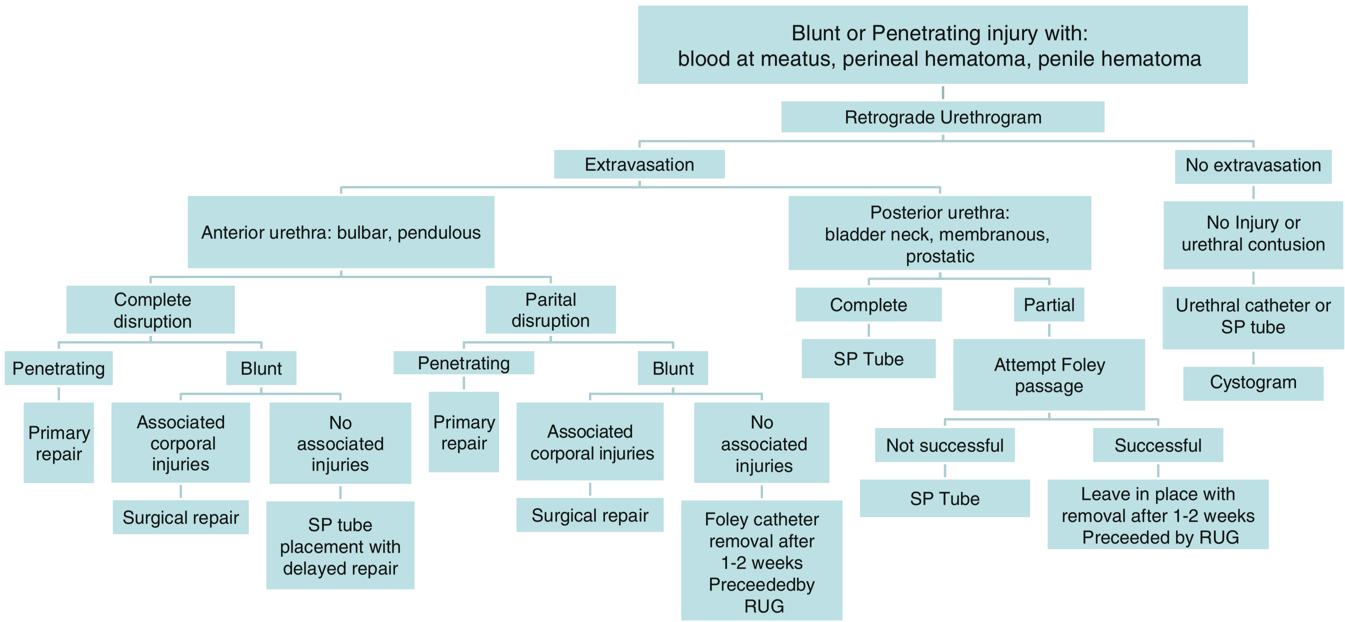

Fig. 23.2 Proposed algorithm for workup of perineal/scrotal/penile trauma. Evaluation of the urethra should be completed prior to proceeding with cystogram. This algorithm assumes there is no urologic surgeon available

urethra ventrally into a neo-meatus, and closure of the remaining skin. These injuries will require urinary diversion with a urethral catheter or suprapubic tube until medical evacuation.

Urethra

Any penetrating or blunt trauma to the penis, perineum, scrotum, or pelvis may include the injury to the urethra. The urethra should be completely evaluated prior to surgery with a retrograde urethrogram. A delayed or missed diagnosis of a significant urethral injury can have devastating consequences including urinoma, abscess formation, infection, and urethral stricture. When considering isolated urethral trauma it is best to classify these injuries based on location rather than mechanism of injury. Urethral injuries in the male can be subdivided into posterior and anterior.

The posterior urethra includes the bladder neck, prostatic urethra, and membranous urethra. In men with pelvic fracture, 10% will also have a concomitant urethral injury – so a high index of suspicion is required. In the posterior urethra, injury is most commonly from blunt trauma where the membranous urethra is distracted from the prostate at the apex, resulting in a pelvic fracture urethral distraction defect (Fig. 23.3). The membranous urethra is most commonly involved in these injuries because the prostate is protected by ligaments which secure it to the pelvis. This is what results in a high riding prostate, the physical exam finding of a prostate that is displaced cranially and difficult to palpate. On radiographic evaluation, a high riding prostate is otherwise known as the "pie in sky" bladder on cystogram.

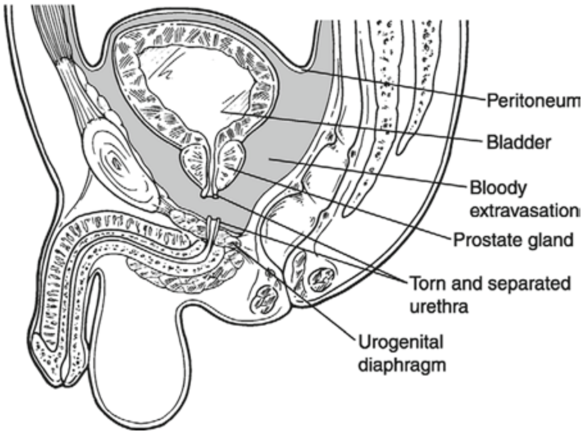

Fig. 23.3 Posterior urethral injury with detachment from the prostate gland resulting in "high-riding" prostate due to gland retraction, and bloody extravasation causing peri-prostatic hematoma. (Reprinted with permission from Rosenstein and McAninch. Med Clin North Am 2004;88:495–518)

Management of the prostatic or membranous urethral injury resulting from high velocity projectiles is best achieved with suprapubic drainage and a Foley catheter placement if possible. A diverting colostomy is often required as there are frequently other injuries of the distal gastrointestinal tract. Early attempt at repair is not indicated as it may cause a significant amount of bleeding, incontinence, and erectile dysfunction. In the case of blunt trauma causing urethral distraction defect, initial management has been hotly debated in the literature. Some authors recommend early realignment of the urethra through endoscopic techniques while others recommend early suprapubic drainage only with a delayed repair after 3–6 months of healing. Currently our thoughts are that the latter is the more logical in the combat trauma setting as it allows acute decompression of the urinary system, convalescence of the patient, and a definitive reconstruction at a controlled time. There are, however, some cases that require early laparotomy with pelvic exploration and repair of the distraction. These include concomitant injury to the rectum or bowel, concomitant bladder neck injury requiring closure, and large distraction defect where the pelvic hematoma needs to be drained acutely. Exercise caution in exploring a pelvic hematoma with a pelvic fracture as it can cause troublesome bleeding.

Anterior urethral injuries can be subdivided into pendulous and bulbar location. The bulbar urethral injuries are typically caused by blunt trauma consisting of a straddle injury or direct blow to the perineum where the urethra is crushed against the pubic bone. These may present with butterfly hematoma on the perineum as well as scrotal hematoma and blood at the meatus. The pendulous urethra may also be injured by straddle trauma or direct blows to the penis which present with sleeve hematomas of the penis where the blood is confined to Buck's fascia.

Penetrating wounds can also cause bulbar, pendulous, or posterior urethral injuries. These typically are from high velocity gunshot wounds or low velocity penetrating trauma from explosive devices. Treatment of any penetrating injury to the urethra classically consisted of simple suprapubic tube or Foley catheter urinary diversion to allow the injury to heal. Recent reports, however, have indicated that exploration with primary closure of the penetrating injury to the urethra results in a better long-term outcome with decreased scar and stricture formation. When urethral injury is found on surgical exploration, the edges need to be carefully debrided and the penetration or laceration to the urethra closed with interrupted fine absorbable sutures such as 4 or 5-0 Vicryl. At that point, leave a small Foley catheter (12–14 French) in place for 3 weeks. A pericatheter retrograde urethrogram should be performed to show no extravasation of contrast prior to removal of the catheter (Fig. 23.2). If the urethral injury is too significant for an acute repair, or there is too much tissue loss for adequate debridement and closure, place a suprapubic tube in order to stabilize the patient for transport and a definitive repair at a later date.

Overall there are three valid options for management of urethral trauma regardless of the location and mechanism of injury: (1) Immediate suprapubic tube placement with delayed urethral repair; (2) Immediate realignment by placing a catheter across the urethral injury with delayed urethral repair; and (3) Immediate repair with surgical anastomosis of the urethral destruction or penetration.

Scrotum and Testicles

The scrotal contents may be significantly injured by both penetrating and blunt trauma. Non-penetrating injuries resulting from crush or saddle injuries to the penis, scrotum, and perineum can cause significant damage to the internal structures without disrupting the skin. High index of suspicion is needed in these instances. The scrotum is much more often involved in penetrating trauma than the penis and prompt surgical exploration is recommended in these cases. In the combat setting there is no reliable method to establish whether the testicles or spermatic cords are involved; hence, prompt surgical exploration is recommended for all these cases. Should one want to perform imaging of the scrotal contents with the goal of avoiding exploration, scrotal ultrasound is the modality of choice and the most sensitive finding for injury to the testicle is the presence of heterogeneity within the testicle. Otherwise, the study is often of no use in this clinical setting. The urethra still needs to be evaluated prior to exploration per the outline in Fig. 23.2.

Access the scrotum through a midline median raphae incision where both of the hemiscrotal compartments can be opened and both testicles delivered, inspected and repaired (Fig. 23.4). During this procedure it is important to note that the lateral raphae, the crevice between the epididymis and the testicle, should always lie laterally in an anatomically normal testicle (Fig. 23.5). This is a good landmark for orientation while placing the testicles back into the scrotal compartment after exploration and avoids twisting of the testicle with possible concomitant ischemia from torsion. When the testicle is injured and the tunica albuginea has been

Fig. 23.4 Penetrating trauma to the scrotum with damage to the ipselateral testicle. This amount of tunical loss is easily closed with running vicryl suture for testicle preservation. The RUG prior to scrotal exploration was normal

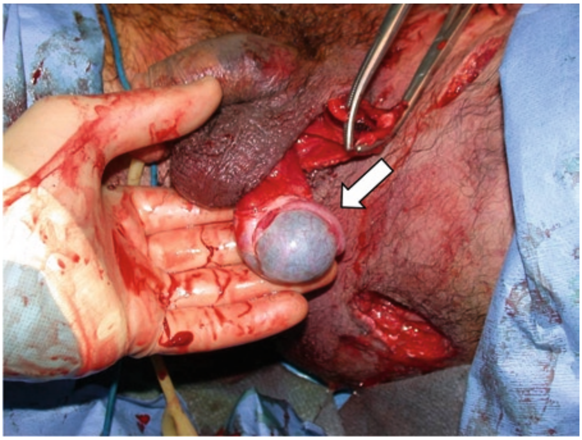

Fig. 23.5 The contralateral testicle is easily delivered through the same incision and inspected. Note the normal anatomy with the lateral sulcus between the testicle and epididymis (*arrow*)

ruptured or lacerated, any extruded seminiferous tubules should be debrided and the tunica closed with running 2-0 Vicryl suture for a watertight repair. If there is not enough tunica albuginea left after the injury to successfully close the testicle, the testicle must be removed in order to avoid the accumulation of necrotic debris or abscess and hematoma formation (Fig. 23.6). The testicles should be placed back into their respective hemiscrotal compartments in the normal anatomic alignment and the compartments closed with running 3-0 Vicryl suture. The skin can be closed with a running 4-0 absorbable suture.

There is rarely a need to leave the scrotal wound open unless it has been severely contaminated with debris, necrotic material, or abscess formation. Do not hesitate to perform an orchiectomy on one side. Orchiectomy may be required in up to 90% of penetrating trauma cases and the remaining testicle will provide enough testosterone for normal sexual characteristic maintenance as well as fertility. If bilateral orchiectomy may be indicated, consider damage control maneuvers – hemorrhage control, irrigation, and debridement of contamination of the scrotum – followed by evacuation to a urologist, if possible. If this is not possible, consider photographic documentation of the extent of injury before proceeding with bilateral orchiectomy. Multiple testicle prostheses currently exist which are excellent and easily placed after completed convalescence. It is always a good idea to leave a Penrose drain in each of the hemiscrotal compartments for 24 h to allow drainage. Because of the elasticity and redundancy of the scrotal skin it is almost always possible to close a scrotal laceration even after significant debridement and tissue loss. However, for very complex and large avulsion injuries it may be necessary to apply local wound care for 12–24 h to allow the edges to clearly demarcate for further debridement. After this, one can try to close the scrotal wound in stages. In some cases skin grafting may be required at a later time for formal reconstruction. In the rare case where there is significant avulsion or tissue injury requiring removal of the entire scrotum and the testicles have no covering it may be required to place them into thigh pouches. This can be easily done by making

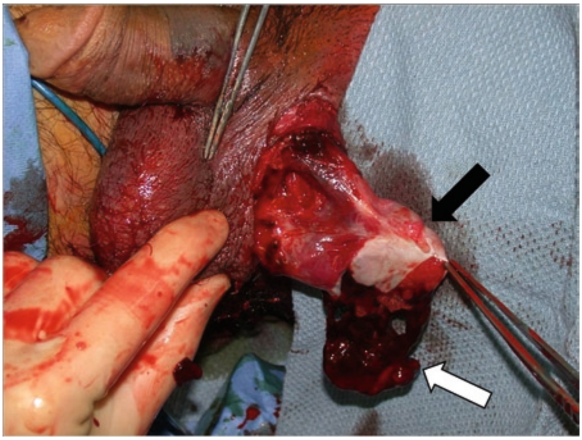

Fig. 23.6 Trauma to the scrotum and testicle with significant loss of the tunica albuginea (*black arrow*) and extrusion of seminiferous tubules (*white arrow*). There is not enough tunica left in this case to preserve the testicle and it must be removed

a tunnel from the perineal/scrotal incision or wound into a subcutaneous thigh pouch on the ipsilateral medial thigh. This will allow delayed reconstruction with skin grafting to the perineum and scrotum, after which the testicles can be removed from the thigh pouches and placed back in the midline.

Bladder

Bladder injuries can be divided into intraperitoneal and extraperitoneal injuries. Intraperitoneal injuries typically are caused by penetrating trauma, pelvic fractures, or blunt insults to the abdomen with a full bladder. These require exploratory laparotomy and watertight closure of the bladder injury in multiple layers with absorbable suture. Extraperitoneal ruptures are usually associated with pelvic fractures such as pubic rami fractures and fractures of the iliac bones. Many of these can be managed with simple catheter drainage, but complex injuries or those associated with pelvic fractures are often better managed by surgical repair. When a laparotomy is required for other reasons it is also recommended to explore and close the bladder injury.

To approach the bladder during exploration, make a vertical midline skin incision from the symphysis pubis to 2–3 fingerbreadths below the umbilicus. Incise the external oblique fascia and split the rectus muscles in the midline. It is not necessary to separate them from their insertion on the pubic bone. Stay extraperitoneal and identify the bladder in the midline. Place two silk stay sutures on each side of the dome of the bladder and make a vertical incision in the dome of the bladder with electrocautery or knife. When performing a laparotomy, if the bladder injury is not easily identified, retrograde instillation of methylene blue through the urethral catheter may help identify the leak. In all cases, perform a cystotomy large enough to allow internal inspection of the bladder and identification of all injuries. Close the injuries with running absorbable 3-0 and 4-0 suture for watertight closures. The placement of a suprapubic tube is controversial, and is unnecessary for most injuries as long as an adequate caliber trans-urethral catheter is in place. A suprapubic tube should be placed for all complex injuries or if there is a concurrent urethral injury. Placement of a drain in the space of Retzius is appropriate in order to pick up any persistent leakage.

After closure of any bladder injury, obtain a cystogram 2–3 weeks postoperatively prior to the Foley catheter removal. If a suprapubic tube was placed in addition to a Foley catheter, the best approach is to leave the suprapubic tube in place clamped for 3–4 days after removal of the Foley catheter thereby serving as a pop-off valve or emergency drain should the patient not be able to urinate immediately after removal of the Foley catheter.

Ureter

Ureteral injuries are extremely uncommon with blunt trauma, but are often seen with penetrating combat wounds. Any injury to the iliac vessels, bladder, or ascending and descending/sigmoid portions of the colon should prompt immediate identification and exploration of the ureter. In addition, you can have the anesthesia provider administer intravenous methylene blue and observe for extravasation – but this DOES NOT substitute for adequate exploration. Base your management of the injury on the portion of the ureter involved and the patient stability. Remember that ureteral injuries are NEVER life-threatening emergencies that require immediate repair. In a damage control setting, the best thing to do is simply establish drainage and leave repair for a subsequent operation.

You must appreciate the anatomy of the ureter as identification can be difficult, particularly in obese patients or in a bloody and injured field (Fig. 23.7). The colon must be mobilized medially, sweeping the mesentery with it and the retroperitoneal tissue (including gonadal vessels and ureter) away from it. If you are having trouble finding it, trace the iliac artery to its bifurcation, and the ureter should be running directly over the bifurcation from lateral to medial.

For a simple transection or laceration of the mid or proximal ureter, perform a primary repair over a “double-J” stent. Spatulate the ends of the ureter after debridement of the injury and place multiple interrupted absorbable sutures to create a circumferential anastomosis (Fig. 23.8). If the distal ureter has been injured, then it should be debrided and re-implanted into the bladder. A simple technique is shown in Fig. 23.9. If the ureter will not reach the bladder due to mobility and tissue loss, then you can bring the bladder to the ureter using a psoas hitch technique (Fig. 23.10). Although techniques of hooking the injured ureter into the contra-lateral uninjured one are described, they should be avoided in most trauma situations. In some situations with combined severe abdominal injuries and a destructive ureteral injury, the patient may be better off with a nephrectomy rather than attempts at complex reconstructive procedures.

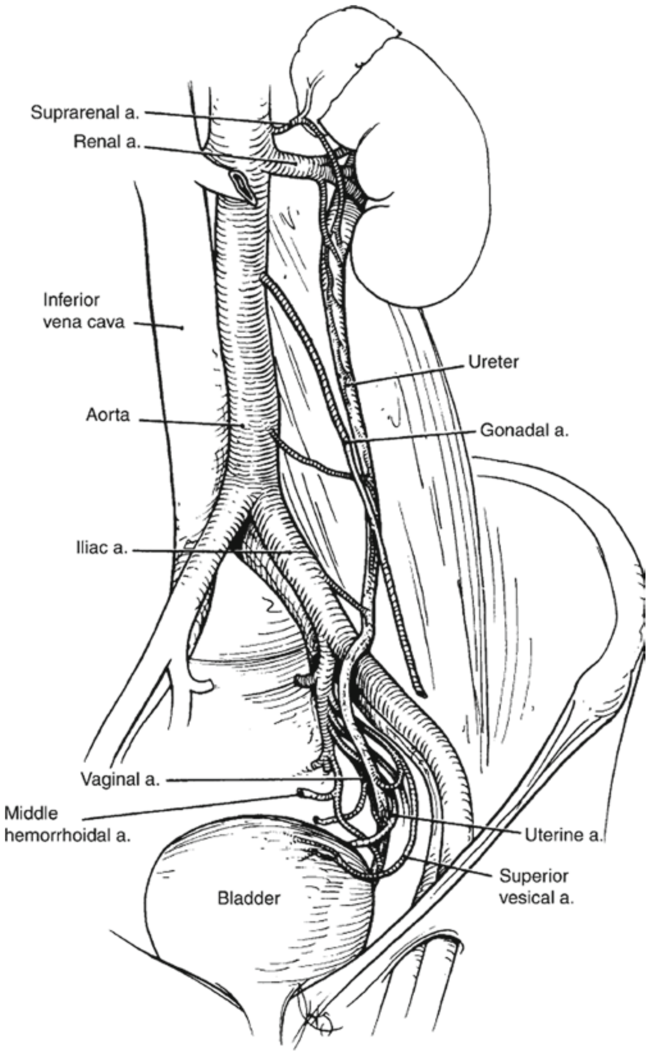

Fig. 23.7 Anatomic course and relationships of the ureter. (Reprinted with permission from Elliott and McAninch. Urol Clin North Am 2006;33:55–66)

Tips and Techniques

Difficult Foley Placement

There are several reasons for the inability to place a bladder catheter through the urethra including urethral stricture, prostate enlargement, difficult to negotiate bladder neck, bladder neck stricture, or obstructing foreign body or tumors.

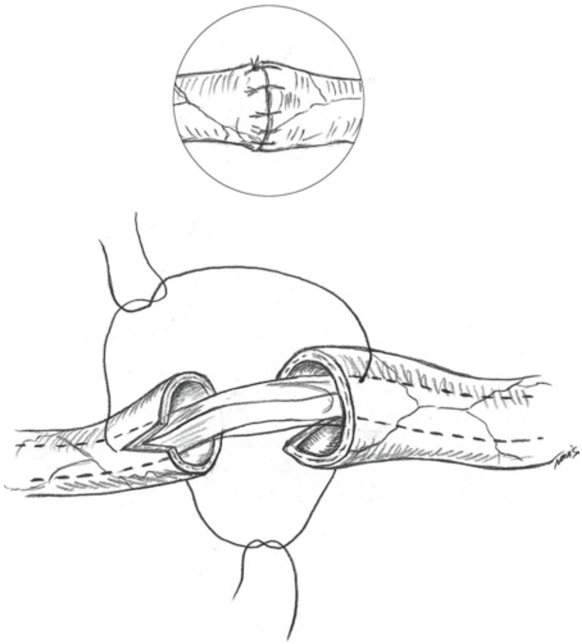

Fig. 23.8 Technique for primary ureteral repair (ureteroureterostomy). The debrided ends of the ureter are spatulated and repaired over a stent using multiple absorbable interrupted sutures to achieve a water-tight seal. (Reproduced with permission from Santucci and Williams. Ureteral Trauma in Emedicine Urology (http://emedicine.medscape.com/article/440933), Medscape 2009)

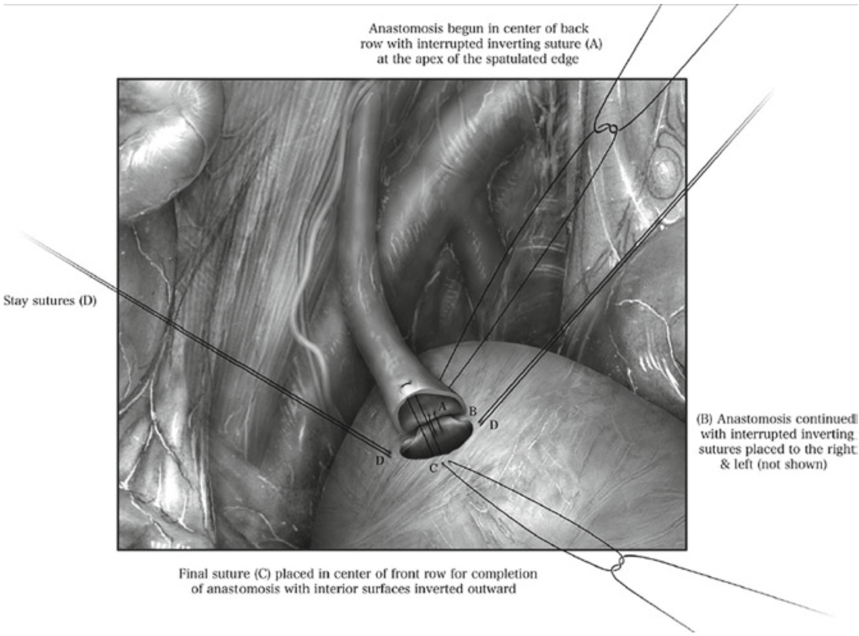

Fig. 23.9 Technique for ureteral reimplantation into bladder (ureterocystostomy). (Reprinted with permission from LaFontaine, P. Operative Techniques in General Surgery 2007;9:167–174)

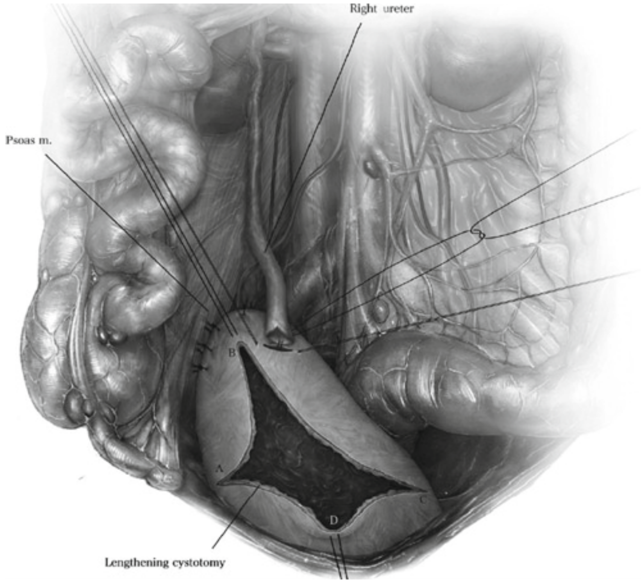

Fig. 23.10 Technique for performing a psoas hitch procedure. The bladder is elongated by creation of a long cystotomy (**a** and **b**), secured to the psoas muscle, and then a tension free ureteral reimplantation is performed. The cystotomy is then closed in two layers. (Reprinted with permission from LaFontaine, P. Operative Techniques in General Surgery 2007;9:167–174)

The majority of the time, a Foley catheter cannot be placed by a medic or nursing staff because of technique. We have found the "hyperlube" technique to be very helpful in these circumstances. If this is unsuccessful then cystourethroscopy or retrograde urethrogram is indicated to rule out a mechanical obstruction. Should one find an obstruction such as a urethral stricture, the best choice for initial management is placement of a suprapubic tube with no further manipulation and delayed surgical repair after evacuation.

The "Hyperlube" Technique of Foley Catheter Placement

Place the patient supine on the examination table. Fill a Toomey syringe with 30 cc of lidocaine jelly and prep and drape the patient's penis in the usual fashion that would be required for Foley catheter placement. Infuse the lidocaine jelly in a retrograde fashion into the penis by placing the tip of the Toomey syringe into the meatus of the penis. After infusing 20–30 cc of the lidocaine jelly retrograde into the urethra, grasp and hold the glans of the penis in order to keep the lidocaine jelly within the urethra. After allowing 2–3 min for anesthesia a Foley catheter is then easily inserted, oftentimes successfully negotiating any portion of the urethra where obstruction was encountered on prior attempts.

We find that the lidocaine jelly helps the patient relax the external sphincter and distends the urethra to allow the catheter to slide through a pool of jelly rather than scrape along the side of the urethra. Again, should this technique not be successful on one or two attempts, obtain a retrograde urethrogram or cystourethroscopy to rule out any mechanical obstruction and consider placement of a suprapubic tube as described below.

Suprapubic Tube Placement

Suprapubic cystotomy is a simple procedure that may be placed with an open or percutaneous technique. To place a well-functioning suprapubic tube that has minimal discomfort one must observe simple certain rules. Common errors in the placement of suprapubic tubes include placing it too low on the abdomen and too low inside the bladder. The latter may cause the tip of the tube to contact and irritate the trigone of the bladder, leading to significant urgency and frequency. Placing a suprapubic tube too low on the abdominal wall may cause irritation against the symphysis pubis and periosteum leading to bone irritation and pain while walking. Another common error includes placing the suprapubic tube through the peritoneal cavity rather than leaving it in the space of Retzius. This may result in leakage of urine into the peritoneal cavity if the tube becomes loose or dislodged. It is important to restate that all sutures in the bladder should be absorbable, as any non-absorbable suture will lead to stone formation and difficulty in the later management of the patient.

Open Suprapubic Tube

Make a vertical midline skin incision from the symphysis pubis to 2–3 fingerbreadths below the umbilicus. Incise the external oblique fascia and split the rectus muscles in the midline. It is not necessary to separate them from their insertion on the pubic bone. Stay extraperitoneal and identify the bladder in the midline as it likely will be full of urine at this point. Place two silk stay sutures on each side of the dome of the bladder and make a vertical incision in the dome of the bladder with electrocautery or knife. Once urine is obtained, extend the cystotomy in order to provide inspection of the inside of the bladder should there be concomitant bladder injuries. Place a 20–24 French Foley catheter through the cystotomy and close the opening with a purse string suture of absorbable 2-0 or 3-0 Vicryl suture for watertight closure. Inflate the balloon on the suprapubic tube with 10 cc of sterile water. Bring out the suprapubic tube through the inferior portion of the abdominal wound or through a separate stab incision only 2–3 cm lateral to the wound. Place tension on the suprapubic tube to bring the cystotomy in contact with the anterior abdominal wall in order to reduce leakage. Secure the suprapubic tube to the skin with a permanent nylon suture.

Percutaneous Placement of the Suprapubic Tube

A percutaneous cystotomy tube may need to be placed in situations where alaparotomy is not required. Successful placement requires some planning. Place the patient supine on a stretcher in as steep Trendelenburg as can be tolerated to pull the bowels away from the dome of the bladder. If the bladder is fully distended with urine it should be palpable in the lower abdomen. If ultrasound is available, this can be used to help guide the placement. Make a puncture incision 3–4 fingerbreadths above the symphysis pubis in the midline. One can use a finder needle in order to establish the depth needed to penetrate and obtain urine. Place a trocar into the dome of the bladder at a 45° angle with the tip of the finder needle directed caudally. Once urine is obtained with a puncture cystotomy tube, it is important to advance the tube 1–2 cm deeper prior to inflating the balloon in order to ensure that the balloon is within the dome of the bladder. Once placed, inflate the balloon with 10 cc of sterile water and place tension on the suprapubic tube in order to pull the dome of the bladder flush with the anterior abdominal wall. Secure the tube to the skin with nylon suture.

Performance of the Retrograde Urethrogram

To perform an appropriate retrograde urethrogram preparation is paramount. It is important to gather the supplies needed first. These include: a 60 cc Toomey syringe, lidocaine jelly, Betadine swabs, Cysto-Conray or Renografin, 4×4 sponges, fluoroscopy.

The patient must be appropriately positioned for the scout film. The retrograde urethrogram should be performed in a semi-oblique position (Fig. 23.11). This is necessary in order to fully view the entire urethra as many injuries in the posterior urethra and proximal bulbar urethra can be missed on an anterior–posterior film. To verify appropriate amount of oblique, the obturator fossa should be obliterated on the scout film (Fig. 23.12).

One should mix 40 cc of contrast material (specifically Cysto-Conray if available) in 10 cc of lidocaine jelly and place this into the Toomey syringe with sterile technique. Prep the penis with Betadine swabs at the tip of the penis. Use sterile gloves and place 4×4 sterile gauze under the tip of the penis. Grasp the penis and instill the contrast solution into the penis in a retrograde fashion. Place the tip of the Toomey syringe inside the meatus of the penis and grasp the glans of the penis with the non-dominant hand. Then under fluoroscopy, bend the penis downward in order to view the location of the suspensory ligament of the penis (Fig. 23.12). Under fluoroscopy retrograde infusion of the contrast is placed into the penis until it can be seen to fill the entire urethra and a small amount can be seen to infuse into the bladder. Afterward, allow the patient to void in the same position to show complete emptying of the contrast from the system thus providing a voiding phase of the retrograde urethrogram.

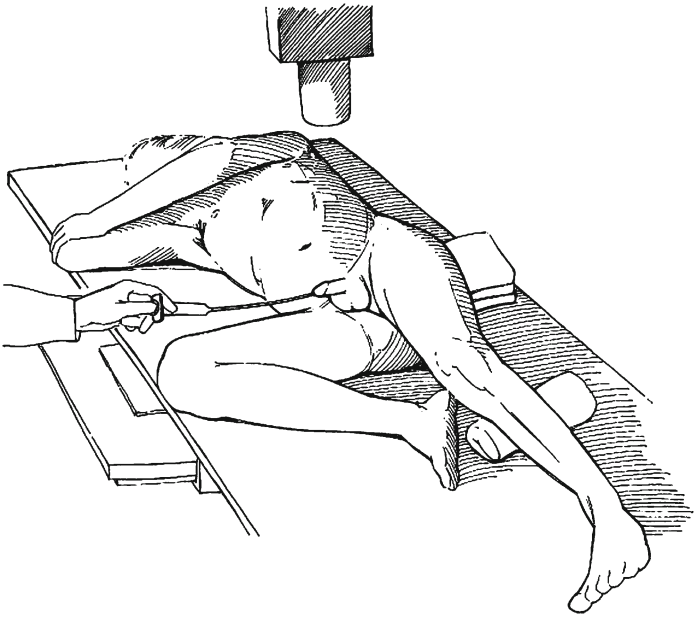

Fig. 23.11 The appropriate positioning for a retrograde urethrogram (RUG). The patient is oblique with a role placed under the top leg and the bottom leg bent. The RUG is performed with fluouroscopy. (Reprinted with permission from Rosenstein and Alsikafi. Urol Clin North Am 2006;33:73–85)

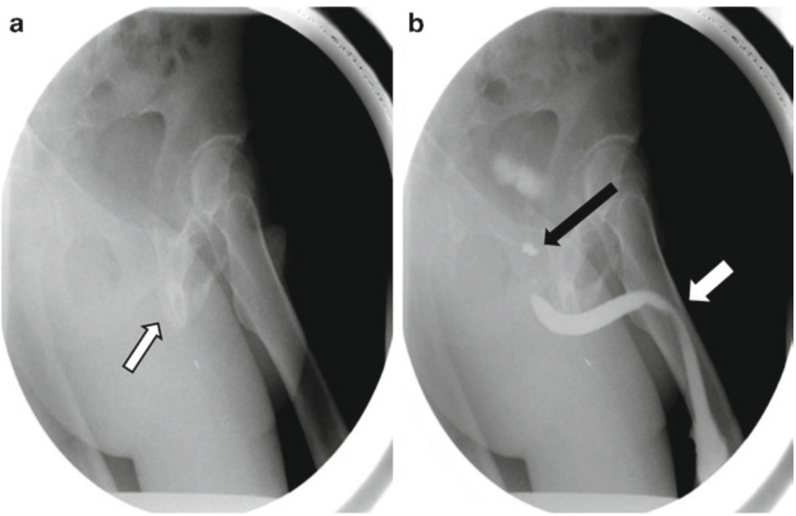

Fig. 23.12 (**a**) The appropriate scout film for the retrograde urethrogram (RUG). The patient is in the oblique position, the right obturator fossa is visible and the left is not (*arrow*) indicating appropriate positioning. (**b**) The RUG is performed showing small amount of contrast extravasation at the membranous-prostatic urethra indicating injury (*black arrow*). The suspensory ligament of the penis demarcates the separation of the pendulous urethra from the bulbar urethra (*white arrow*). Note the small piece of shrapnel in the patient's thigh

Performance of the Cystogram

Prior to performing a cystogram, if there is any question of a urethral injury it is best to obtain a retrograde urethrogram (Fig. 23.2). Place a Foley catheter into the bladder. You may perform a cystogram with fluoroscopy or CT scan imaging if available. If fluoroscopy is chosen, scout anterior–posterior films are required to ensure no calcifications, foreign bodies or fragments are present. Fill the bladder retrograde to 350 cc of Cysto-Conray or an appropriate contrast agent under gravity. Under no circumstances should you force contrast into the bladder with a Toomey syringe or with pressure. After instilling 350 cc, clamp the Foley catheter and obtain anterior–posterior films with oblique films. Allow the bladder to empty and obtain films to ensure no contrast is left behind, indicating a possible injury to the posterior bladder wall that may be missed on anterior–posterior imaging. Do not rely on antegrade filling of the bladder with excreted IV contrast as this will miss injuries in up to 20% of cases. The filling must be retrograde.

Should CT scan be available, no scout or emptying films are needed as the CT scanner provides 360° evaluation of the bladder. Place a Foley catheter only after any injury to the urethra is excluded with a retrograde urethrogram or cystourethroscopy. Again, instill 350 cc of contrast into the bladder under gravity in a retrograde fashion. CT scanning through the pelvis should show the bladder to be smooth-walled with no extravasation and in the bladder may be drained with no further imaging needed.

It is imperative to fill the bladder only under gravity and not to force any contrast into the bladder as this may induce an iatrogenic injury. The optimum volume to fill into an adult is 350 cc as multiple studies have indicated that any less may miss some bladder injuries.

Summary

The deployed general surgeon will be called upon to manage a wide variety of combat trauma related injuries to the external genitalia and lower urinary tract. The majority of the injuries to the perineum and scrotum are from explosions. These include blunt injuries, penetrating injuries, crush injuries, burns, or a combination of all of these mechanisms. Most of these injuries can be accurately diagnosed with physical exam and simple imaging studies, and the mainstay of treatment is direct surgical exploration and repair. Because most general surgeons do not get much exposure to such cases in their peacetime jobs, it is imperative that the deploying surgeon review the basic management principles as described in this chapter. Such review will allow the surgeon to successfully manage or at least temporize the majority of the lower genitourinary injuries encountered.

Chapter 24
Neurosurgery for Dummies

Hans Bakken

Deployment Experience:

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Commander, 207th MED DET, Air Force Theater Hospital, Joint Base Balad, Iraq, 2008–2009

BLUF Box (Bottom Line Up Front)

1. "A B and C" come before "N".
2. The presence of a serious head injury must not impede the resuscitation of the trauma patient. (a gruesome 'distracting' injury can distract the physician as well as the patient.).
3. Normotension, Normovolemia, Normoventilation and Normothermia must prevail in the brain injured patient. Time = neurons, so act immediately and decisively.
4. In patients with suspected ICP problems or mass lesions, the use of hypertonic saline is preferred over mannitol, especially in the multiply injured patient.
5. The primary role of the trauma surgeon in the head injured patient is to follow point 3 above.
6. Do not transfer the unstable head injured patient because you don't have a neurosurgeon – see point 2 above.
7. Timely transfer of the stabilized head injured patient to a Neurosurgeon is generally the best way to treat a severe head injury after initial stabilization.
8. A trauma craniectomy or ICP monitor can be safely performed by a general surgeon who understands the indications, technique (described here), and complications.
9. Be aggressive early, but know when to quit – resources are scarce and should not be used on non-survivable injuries or injuries with a very low probability of meaningful recovery.

The abdomen, the chest, and the brain will forever be shut from the intrusion of the wise and humane surgeon.

John Erichsen, 1818–1896

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Introduction

During one of the editors first week in Iraq, a soldier with an obvious severe head injury from a roadside bomb was brought in. He was rapidly tagged as “needing urgent transfer” to the neurosurgery team in Balad. While waiting for the helicopter his nurse fortunately noted that he was becoming more hypotensive, and alerted one of the trauma surgeons. A more thorough evaluation was performed, a FAST exam demonstrated hemoperitoneum, and the patient underwent emergent splenectomy with subsequent rapid stabilization and then transfer. The most important point of this chapter is: *The presence of a head injury should not change the initial treatment of the trauma patient.* As a corollary, the premature transfer of a trauma patient to a Neurosurgeon prior to appropriate initial treatment will adversely affect outcomes.

War-related trauma differs significantly from trauma seen in the civilian world. The prevalence of burn, penetrating and blast injuries sets the stage, and a multitude of other factors, including environmental conditions (e.g. mountains and deserts), physical settings (e.g. tents), and supply issues serve to make the wartime physician’s job worlds apart from anything else on the planet. Setting aside uniquely military aspects of being in a Theater of Operations (carrying a weapon and wearing body armor), this chapter will provide you with the basic information that you need to care for head-injured patients prior to their transfer to a higher echelon of care.

With medical operations in the various theaters fairly mature after years of combat operations, lack of ready access to a Neurosurgeon in theater is becoming an infrequent problem. However, this access depends on the ability to transport the patient to the proper facility with a neurosurgical team. This means that as the initial receiving physician or surgeon, you *are* the neurosurgeon until that patient is put on a helicopter out of your facility. This results in a number of situations that will require a General or Trauma Surgeon to manage the patient with a head injury, and occasionally even have to perform a neurosurgical operation. This chapter will provide a cookbook-type approach for this initial management, and provide guidance to the general surgeon on when and how to proceed should the situation call for basic Neurosurgical intervention when there is no Neurosurgeon available.

As with other types of traumatic injuries, there are head injuries that are fatal, no matter what intervention is undertaken. The phrase “arrived dead, stayed dead” does apply occasionally, although you do not need to take it upon yourself to determine whether or not a head injury is survivable. Your job is avoiding secondary neurologic injury, most of which can be attributed to decreased oxygen delivery to the brain. If you have optimized the hemodynamics and blood oxygenation, then you have addressed the two most important factors which will save neurons. The third major factor is intracranial pressure (ICP). There are a limited number of maneuvers that you can perform in order to manage ICP, which will be described in the pages to follow. The final steps in the management of refractory ICP are surgical. While this chapter will provide guidelines which will allow a General or Trauma surgeon to perform a decompressive craniectomy with a reasonable degree of safety, the carrying out of that surgical procedure does require a certain degree of surgeon comfort and confidence. The decision to perform a decompressive craniectomy is not an easy one. Only the combination of a known or suspected ICP problem, deteriorating neurologic function, and the unavailability of Neurosurgical care (timely transport via *medevac* assets) should trigger this decision.

The Basics

Glasgow Coma Scale (GCS) is a very simple, yet useful assessment in the head injured population. It gives a reproducible numerical scale from 3 to 15 which correlates very well with outcomes, especially when used to separate "severe" head injuries from all others (mild and moderate). Many times patients will arrive already intubated, or under sedation. In these cases you should attempt to glean a GCS from the *medevac* crew, or piece it together from a *brief* interview with the medics (what was the soldier/patient doing at the scene). Also remember that intubation does not preclude assessing mental status – if the patient is awake or moving, get a good basic neurologic exam before you re-sedate or paralyze. GCS pearl: don't use the "squeeze my fingers" test to determine if the patient is following commands. Grasping can be a reflexive motor function. Tell the patient to do something and observe for the proper response, such as "give me a thumbs up" or "move your left foot".

When Do I Need a CT Scan/What If I Don't Have a CT Scan?

When evaluating patients at a location that has ready access to CT, the following are general indications for obtaining a CT scan of the head:

1. Loss of consciousness
2. Amnesia for the event
3. Abnormal neurological exam
4. Penetrating head injury

Computed Tomography is in such common use that we as physicians find it difficult to fathom evaluating a patient without a "pan-scan". However, there are many locations in a war zone that do not have CT units. Not all trauma patients require evaluation by CT, but if they have a mild head injury they must be *closely* observed for signs of deterioration. Patients that have abnormal head CT findings generally should have the study repeated 6–12 h after the original study, sooner if they deteriorate neurologically.

Most, if not all patients with a penetrating head injury will require treatment by a Neurosurgeon, thus transfer to an appropriate facility should be planned in order to minimize delay after their assessment, stabilization and resuscitation have been initiated. In patients that meet the above criteria for CT scan when there is *no scanner*, transfer to another medical asset needs to be considered *after* appropriate initial stabilization, assessment and resuscitation.

How Do I Know If There Is an "ICP Problem"?

Many people mistakenly think the neurologic exam doesn't come until the secondary survey. After the ABCs have been done, the next step is D – disability. The goal of D is simple – identify significant head injury and any evidence of ICP elevation. This is done by calculating the GCS and examining the pupils. Remember that GCS is a measure of overall cerebral function, not localized neurologic function. A patient can have complete hemiparesis and still have a GCS of 15. You must understand the clinical signs of rising or elevated ICP. These include rapid neurologic deterioration or coma, unilateral or bilateral fixed/dilated pupils, and motor posturing (flexor or extensor). Cushing's triad of hypertension, bradycardia, and altered respirations is a classic response to elevated ICP, and this pattern is rarely seen in non-head injured trauma patients. If these signs are present, begin treatment immediately – you don't need to wait for a CT scan.

After establishing your baseline neurologic exam and initiating any interventions, you then decide on whether the patient needs immediate operation, transfer, or admission. In any case, the patient should have frequent serial neurologic examinations done to immediately identify deterioration (rising ICP) and intervene. A decline in GCS of 2 points in the absence of confounding factors is generally significant, and requires further diagnostic and therapeutic maneuvers. The worse the head injury, the more important a good and detailed neuro exam is! Anyone can pick up a GCS decline from 15 to 13, but identifying a drop from 8 to 6 requires much more attention to detail.

The Isolated Severe Head Injury

CT scan should be obtained if available. Follow the "four N's" from the BLUF box (above). If initial GCS is greater than 8, serial neurological examinations can be used to follow the patient's status. Call the Neurosurgeon on call to let him or her know what you are doing, they will likely provide good advice. If the initial GCS is 8 or less, consider placing an ICP monitor or External Ventricular Drain if available (technique to follow). Employ the ICP management strategy (see the excellent JTTS clinical practice guideline) to keep sustained ICP less than 20. If this cannot be accomplished, consider performing decompressive craniectomy (technique to follow). Decompression should be performed on the side with the most abnormality on CT, or in the absence of CT, laterality can be determined based in the following neurologic findings: (1) Ipsilateral to a penetrating head injury or dilated pupil. (2) Contralateral to a hemiparesis / hemiplegia/babinski's sign. In a patient who has not had neuromuscular blockade, the presence of bilaterally large and unreactive pupils (*without* significant globe injuries), the absence of all cranial nerve reflexes (cough, gag, corneal reflexes), and the absence of any response to peripheral and central noxious stimulation are extremely poor prognostic factors and consideration should be given to treating them as expectant.

Severe Head Injury in the Multiple Trauma Patient

With the increasing prevalence of explosive injury mechanisms in combat trauma, multi-system injury including severe brain trauma is much more common than seen in civilian practice. Blast injuries will often result in a devastating combination of skull fractures, blunt parenchymal injury, and multiple fragmentation injuries (Fig. 24.1). These patients will typically present intubated, and having received sedation and neuromuscular blockade. It is very important to try and obtain a GCS from the scene of the trauma to assess for a head injury. A patient with a low GCS at the scene, even in the absence of physical findings or CT findings consistent with a head injury, may indeed have a severe brain injury. Even with CT at your disposal, patients may harbor unrecognized head injuries. Occasionally, there will be a great deal of effort expended by the Trauma / General surgeons in order to stabilize a patient, after which it is determined that the patient has an extremely poor neurologic prognosis (see paragraph above). Again, consideration must be given to palliating the patient. Also remember that the classic hemodynamic response of hypertension and bradycardia may not be present in the hypovolemic trauma patient.

In a patient who is hemodynamically unstable due to ongoing hemorrhage, resuscitation and assessment need to be initiated in order to save the life of the patient. Once this has occurred, the head injury can be addressed as in the previous scenario. If the patient requires prolonged surgical intervention, place an ICP monitor or EVD in order to optimize the ICP during the surgical procedure. Due to limitations

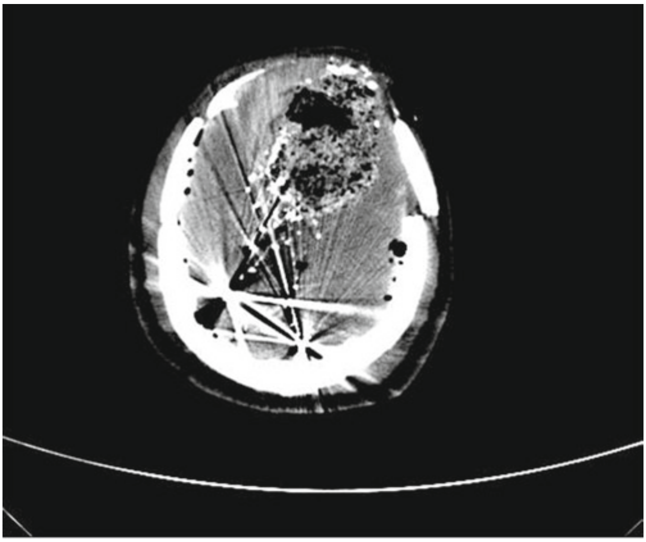

Fig. 24.1 Head CT following a roadside bomb injury. Note the combination of multiple skull fractures, diffuse parenchymal injury and edema, and multiple fragmentation wounds

in positioning, it can be quite difficult to manage ICP during general surgical procedures. If the ICP is refractory, consider decompressive craniectomy in conjunction with the other ongoing trauma procedures.

Placement of ICP Monitor "Bolt" or EVD (Required Kits Must Be Available)

In general, placement of an ICP monitor (or "bolt") is easier than the placement of an EVD, as it is a simple intraparenchymal sensor and does not have to be in a specific location, whereas an EVD is fairly useless unless you actually get it into the ventricle. If the patient has significant edema or midline shift, the ventricle can be very difficult to hit and a bolt should be placed. The main advantages of an EVD over a bolt are that it can be used to both measure ICP and to treat it. The EVD allows for drainage of CSF, which will lower ICP.

Preparation

Normalize coagulation status. Administer 1 g cefazolin IV, if no allergies. Get the equipment. Get an assistant. Get a small stand on which you will place the equipment. You will need: (1) Cranial Access Kit. (The Cranial Access Kit is designed to allow you to place either an ICP monitor or an EVD. There are two drill bits in the kit; you use the small diameter drill bit for ICP, and the big drill bit for EVD. (2) ICP device (Codman) and monitor *OR* EVD kit and drainage bag. Pick a side. Place the monitor or EVD on the side that is already damaged. If there are no lateralizing findings on exam or CT place the device on the right (nondominant) side. Place the patient's head *straight midline*. This will minimize your chance of misplacing the device.

Marking the Patient

Make all markings *prior* to prepping the field. Stand directly behind the patient. First, make a heavy straight line right down the midline. This is your most important landmark. Then, the standard entry point for both an EVD and an ICP monitor is: 13 cm *back* from the nasion (the bridge of the nose) and 3 cm *lateral* to midline (Fig. 24.2). This will be just a bit anterior to the coronal suture. In a very young child, the entry will be 3 cm off midline, and one centimeter anterior to the coronal suture, which should be palpable. Prep a wide area around your marked entry point. Drape out so you can clearly see your markings, including midline.

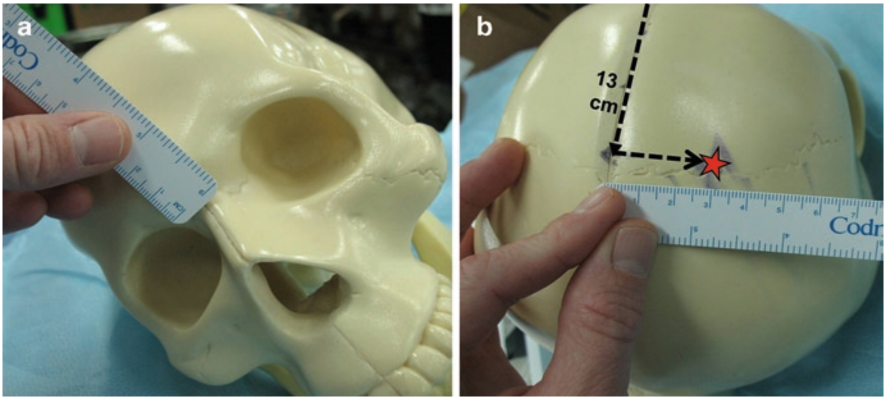

Fig. 24.2 Landmarks for placement of an ICP monitor or ventriculostomy. (**a**) Begin measurement at the nasion (bridge of nose). (**b**) Measure 13 cm back from the nasion and then 3 cm lateral to the midline to identify the entry point (*red star*) for catheter placement

Placing the Device (ICP Monitor)

Use the local anesthetic in the kit, make a wheal under your entry point. Fill one of the wells in the kit with a pool of sterile saline, this will be used to calibrate the transducer. Have your assistant power up the monitor box. Take the small drill bit, and remove the aluminum 'drill stop' using the small allen wrench. Put the bit into the hand drill. The 'bolt' that threads into the skull has a small white plastic donut on the threaded portion. Remove it unless you are placing the bolt into a pediatric patient (thin skull). Make a stab incision directly on your marked entry point. Don't worry about the bleeding. Take the drill and put it directly through the stab, *perpendicular* to the skull (Fig. 24.3a). This small bit is very sharp, and you do not need to exert much downward pressure while drilling. You will feel the drill bit sink into the skull, and after just a few turns, it will drop through the inner table. Don't worry if it seems to plunge, this is an intraparenchymal monitor that you will be sticking into the brain tissue. Remove the drill. Take the spinal needle and insert it into the hole you just drilled. If it stops against the skull, you need to drill more. Once you are through the skull, the needle will puncture the dura and you may see a bit of blood or CSF. Take the 'bolt' and thread it into the hole you just drilled, finger tighten (Fig. 24.3b).

Now take the wire (the actual monitor) taking care not to kink it (it is fiber optic and is easily broken). Your assistant will be holding the female end (non-sterile). Your end has a very small plastic screw which needs to be facing up so you can turn it to calibrate the monitor. You will insert this male end (sterile) and then place the distal end of the wire into the saline pool. The assistant will then press the button to calibrate the monitor. A number will appear on the box, you take the tiny plastic screwdriver and turn it until the number on the box is zero (Fig. 24.4a).

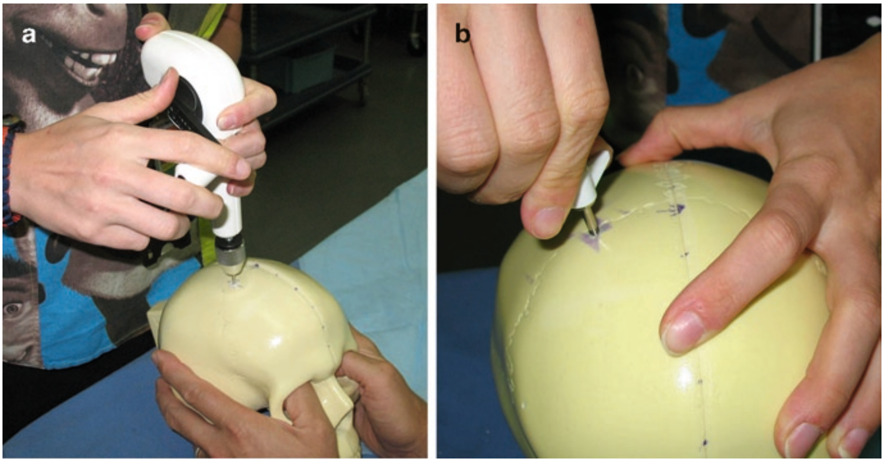

Fig. 24.3 Drill through outer and inner table of skull (**a**) and place the bolt into the hole, screwing it in until finger tight (**b**)

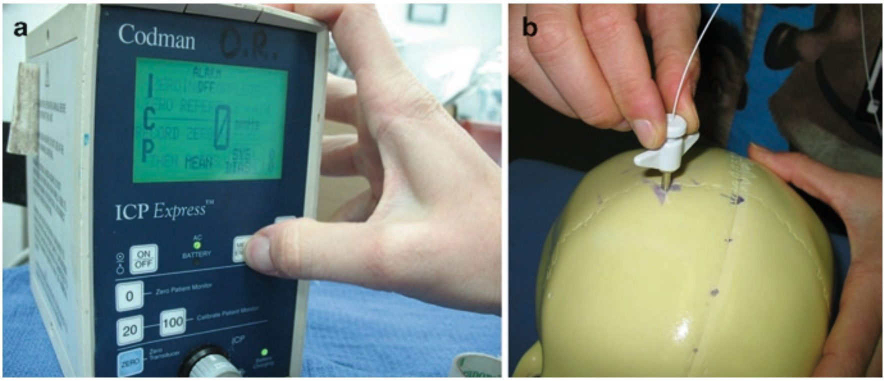

Fig. 24.4 Zero the ICP monitor (**a**) while the catheter tip is submerged in saline. Place the monitor catheter through the bolt and into the brain parenchyma (**b**)

Loosen the white plastic knob on the bolt ½ turn counterclockwise, and take the small metal rod, pass it down the hole in the bolt fully (there is a stop on it) to clear out any bone fragments which might damage the transducer, then remove it. Then insert the wire that you just calibrated up to the double lines (Fig. 24.4b), and tighten the knurled white cap finger tight. Look at the reading on the box. If the reading is extremely high, the monitor is likely pressing on arachnoid, or some other tissue which is falsely elevating the reading. In this case, loosen the knob and pull back slightly on the wire, it should move freely. Make sure that you still have a waveform on the monitor box, and then retighten the cap, then put the seal down over the cap and apply a tape dressing.

Placing an EVD

Essentially the same procedure as above, with the following differences. If you have a CT and the patient has a significant amount of midline shift, it will be very difficult to cannulate the ventricle, thus an ICP monitor is a better choice. There is usually no 'bolt' with this kit. Make a linear incision rather than a stab, and use the small self-retaining retractor to maintain the exposure. The purpose of this incision is to allow you to 'tunnel' the EVD after you pass it into the ventricle. Use the larger drill bit. Once you are through the skull, continue to turn the drill bit forward a few turns while maintaining the same depth in order to remove small fragments of the skull from the hole. You will need to make a large hole in the dura after you drill, in order to be able to pass the EVD. The trocar which is on the EVD itself works well for this (Fig. 24.5a). Pass the sharp end of the trocar through the hole in the skull, you will feel it penetrating the dura, you should pass it about ½ centimeter further once it penetrates the dura. Don't be worried about passing it into the brain, remember, you are going to push a large silastic catheter *through* the brain into the ventricle. Place the inner stylet into the EVD (Fig. 24.5b). Pass the EVD *perpendicular* to the skull;

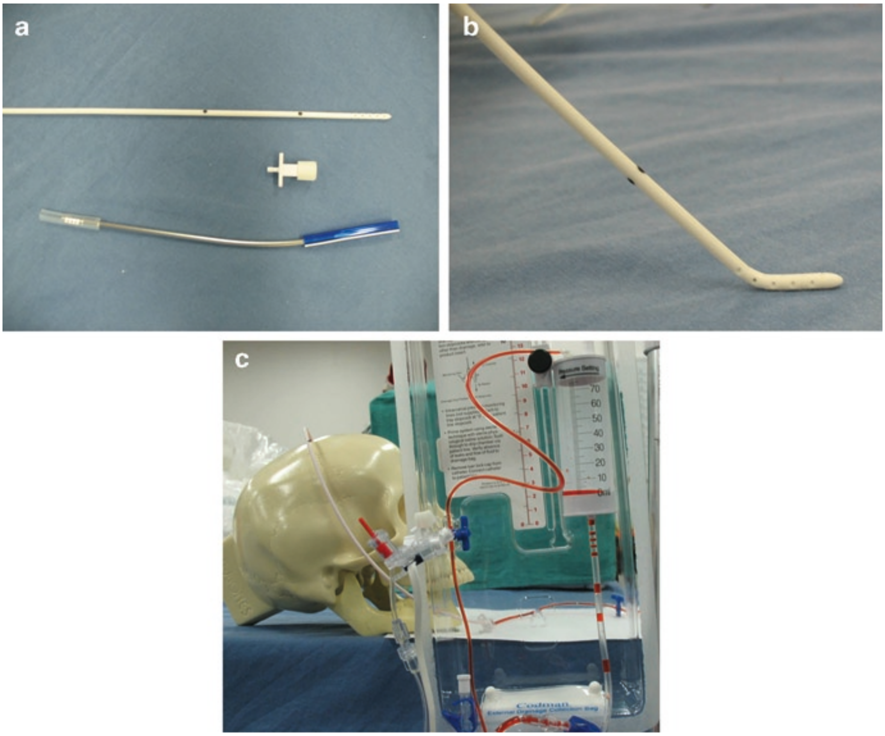

Fig. 24.5 (**a**) Ventriculostomy (EVD) catheter (*top*) and sharp-tipped trocar (*bottom*); (**b**) catheter with stylet inserted to stiffen tip; (**c**) level the drainage kit at the external auditory meatus and then maintain it at 10 cm above the ear

you should feel it 'pop' into the ventricle at about 4–5 cm depth from the surface of the skull. Do not pass it more than 7 cm; the catheter is marked in 5 cm increments on its external surface. After you feel the pop, hold the EVD right at its insertion into the skull with one hand, and use the other hand to withdraw the stylet approximately one centimeter, while maintaining the depth of the EVD. This will allow you to 'soft pass' the EVD to a total depth of 6 cm from the outer table of the skull once you know it is within the ventricle. You may see CSF emanating from around the stylet at this time, and it will likely be blood-tinged.

An assistant with sterile gloves is quite helpful for the next several steps. Taking care to hold the EVD securely at the skull surface, attach the trocar to the proximal end of the catheter and use it to tunnel the catheter for 3 cm laterally and then bring it out through the scalp. Cut the trocar off the EVD, and place the Luer lock adapter into the EVD. Suture the EVD at its exit from the scalp using a roman-sandal type knot, and then close the linear incision. Apply tape and gauze dressings. Level the drainage kit and maintain the drain open at 10 cm above the ear – this should allow CSF to drain if the ICP rises. ICP readings can be obtained hourly by hooking up an arterial line transducer to the stopcock on the drainage bag (do *not* use a pressure bag) and then closing the system distal to the transducer for a few minutes. This will directly measure the CSF pressure, but be sure to open the system again in order to allow drainage.

Decompressive Craniectomy Tips

Only you, as the operative surgeon, can make the call whether or not to perform this procedure. Telephone contact with a Neurosurgeon will likely provide helpful information about indications, especially since you may now have access to web-based radiology systems. Transfer to a Neurosurgeon is always the best option, but craniotomy/craniectomy has been done in both Iraq and Afghanistan by General Surgeons in emergent situations. The utility of the "exploratory burrhole" is limited. If surgical intervention is going to be performed you should proceed directly with a unilateral decompressive craniectomy (laterality based on the lateralizing findings discussed earlier, or on CT findings of mass effect or extra-axial blood, either epidural or subdural). Acute epidural hematomas and subdural hematomas are very difficult to evacuate through burrholes, and you will certainly not be able to identify a source of ongoing bleeding, if it exists. By proceeding directly to the definitive surgical intervention, you will save valuable time and the life of the patient. I will now describe a basic and effective all-purpose operative approach for these cases.

Preparation

When you arrive at your place of duty, inquire as to the status of equipment required to perform a basic craniectomy. At a minimum, you will need a periostial elevator, craniotome with bits, Gigli saws with saw passers and handles, a Leksell rongeur, and a Metzenbaum scissors. Normalize coagulation status (crucial). Type and cross match at least four units PRBC. Give 2 g cefazolin if no allergy. Clip the hair as completely as possible without wasting undue time. Place the head straight midline, and stand directly behind the patient in order to correctly visualize landmarks. *mark the midline!* This is your most important landmark, as you will be staying *away* from it in order to avoid problems (Fig. 24.6). Palpate the zygoma and mark it. Make a gentle, question-mark shaped line from the anterior hairline in the midline extending to the base of the zygoma one centimeter in front of the tragus (Fig. 24.7). Making the skin incision in the midline will make it easy to remember where the midline is, and to stay *away* from it during bony work. Position the patient with a shoulder roll under the ipsilateral shoulder (decreases the amount of tension on the neck), and rotate the head away, fully exposing the craniectomy side. If the patient has a known or suspected cervical spine fracture, be less aggressive with positioning, and consider leaving the cervical collar in place. Place the head on a donut headrest. The head should be nearly lateral when you are done positioning, and elevated above the level of the heart. Prep and drape widely, do not worry about the ear being in the field, it is a good landmark. Incise the scalp all the way down to the bone, beginning at the hairline. Secure the scalp edges with Raney clips as you go. When you get to the temporalis muscle, incise it in line with the scalp incision, use of the monopolar will minimize bleeding. Retract the scalp flap forward and dissect the flap and the temporalis muscle off the surface of the skull along the entire length of the incision (Fig. 24.8). You will need to expose the root of the zygoma, and the posterior edge of the orbital rim. Before drilling the perimeter burrholes, *mark the midline and stay at least 2–3 cm lateral with all bony work* (Fig. 24.9a). With

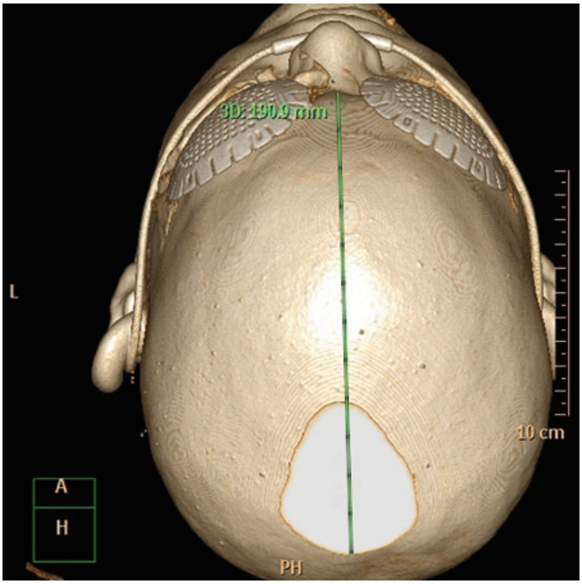

Fig. 24.6 Clearly mark the midline from the bridge of the nose to the occiput

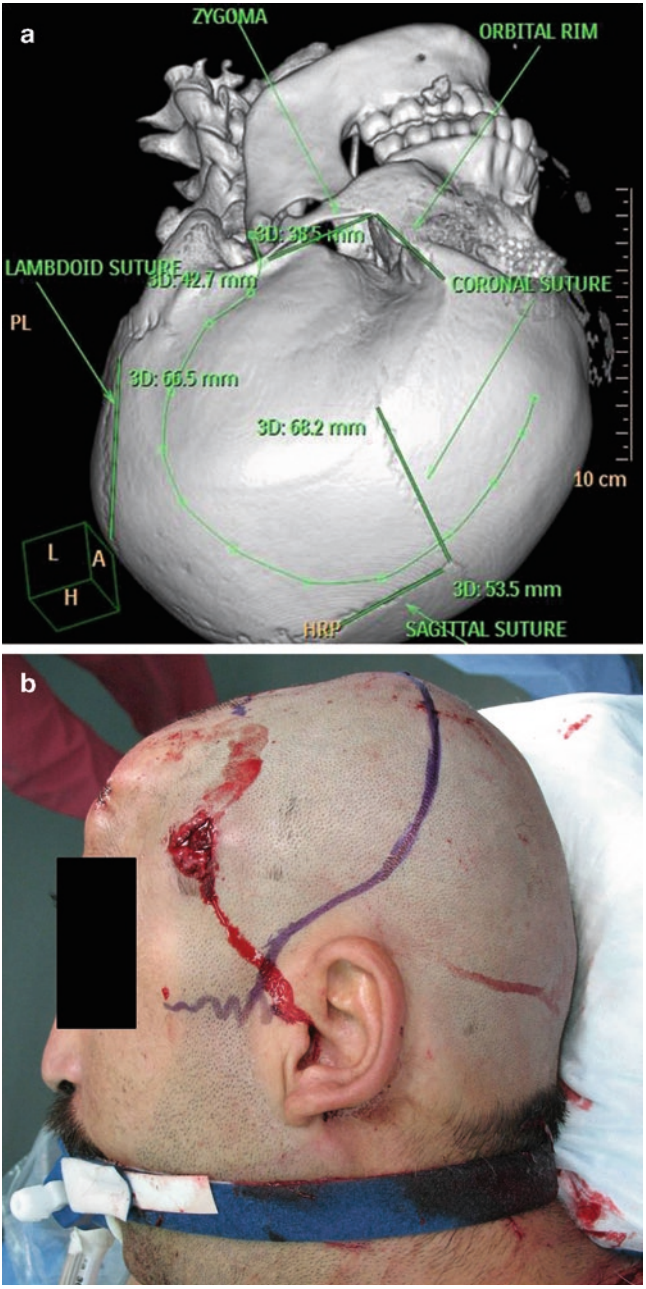

Fig. 24.7 Planned incision is a gentle curve ("question mark") from the midline at the anterior hairline to the base of the zygoma and 1 cm anterior to the tragus. (**a**) Operative surgeon's view and (**b**) lateral view

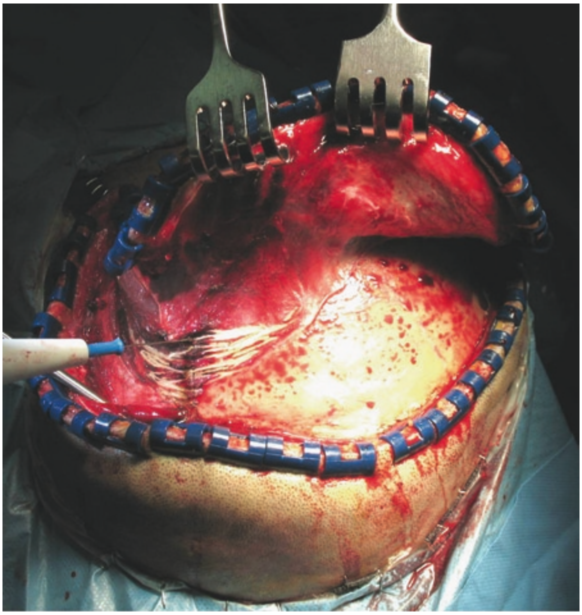

Fig. 24.8 Raise a broad based temporalis muscle flap to expose the underlying skull

the skin incision extending to the midline, you will be able to see and feel the sagittal (midline) suture easily, and your skin edge is also a landmark for midline. Mark each site for the proposed burrholes (6–7 should suffice) and create them (Fig. 24.9b). Use bone wax on your finger for bone bleeding. Use the Penfield no. 3 to circumferentially strip the dura from the inner table of the skull. The Gigli saw set is used to connect the burrholes and complete the 'bone flap'. Place the saw (the wire) over the hook on the 'saw passer', pass from one burrhole to the next, leaving the passer in place, then attach a handle to each end of the saw, and pull back and forth with arms as wide as possible to avoid kinking the saw. Use a fresh saw for each cut. If you can't pass the saw in one direction, try passing it from the other hole. Once you have completed the bone flap, use the periostial elevator to pull up on the edge and sweep it under the flap to free up any last dural adhesions (Fig. 24.10). Remove the flap from the field. In general, do not implant the flap (some recommend 'preserving' the flap in a subcutaneous abdominal pocket for re-implantation). Use a Leksell rongeur to remove the squamous portion of the temporal bone, just above the zygoma. This will decompress the temporal lobe and address 'uncal herniation'.

You must then open the dura. Adson tissue forceps (the ones with teeth) and a sharp no. 15 blade work best (Fig. 24.11a). Make a one centimeter linear score in the dura, pick up the edge with the Adson, and deepen the cut until you obtain CSF. You may lacerate the brain, especially if there is a great deal of edema. Then pick up the dural edge and complete the question-mark shaped durotomy in line

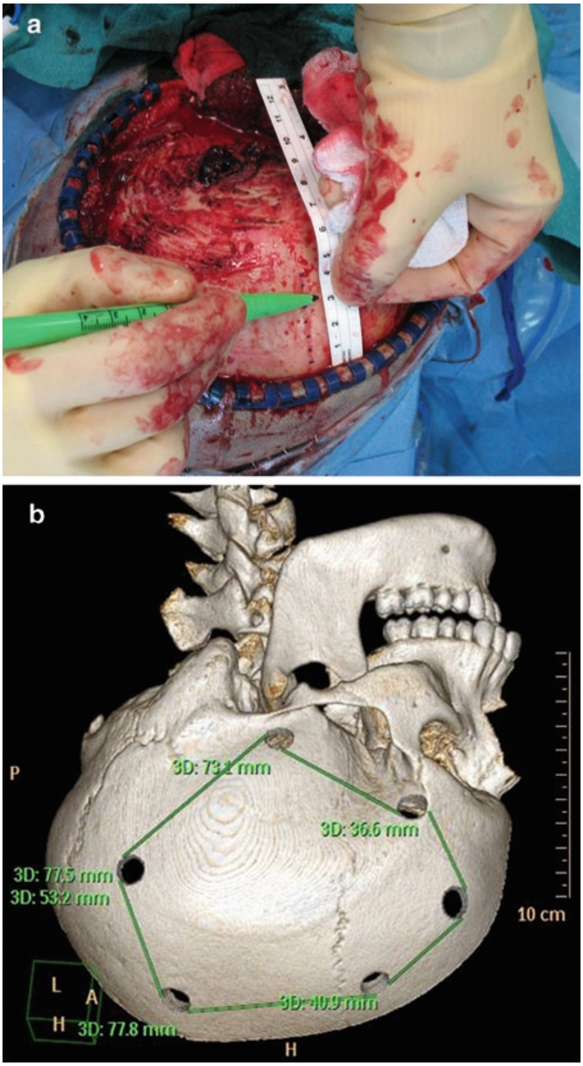

Fig. 24.9 Outline the proposed bone flap, making sure to always stay at least 3 cm off of the midline (**a**). Mark 5 to 6 equally spaced burrholes (**b**)

with, but smaller than, the bone flap, again staying well away from the midline (Fig. 24.11b). If there is active bleeding from a large, visible vessel, use the bipolar coagulator if available, or clamp and tie off. The decompression is now complete (Fig. 24.12). You may now place an ICP monitor or EVD directly at this time. Take the ICP wire from the kit, pass a 14 gauge Angiocath from inside the scalp to outside the scalp across midline near the coronal suture, then pass

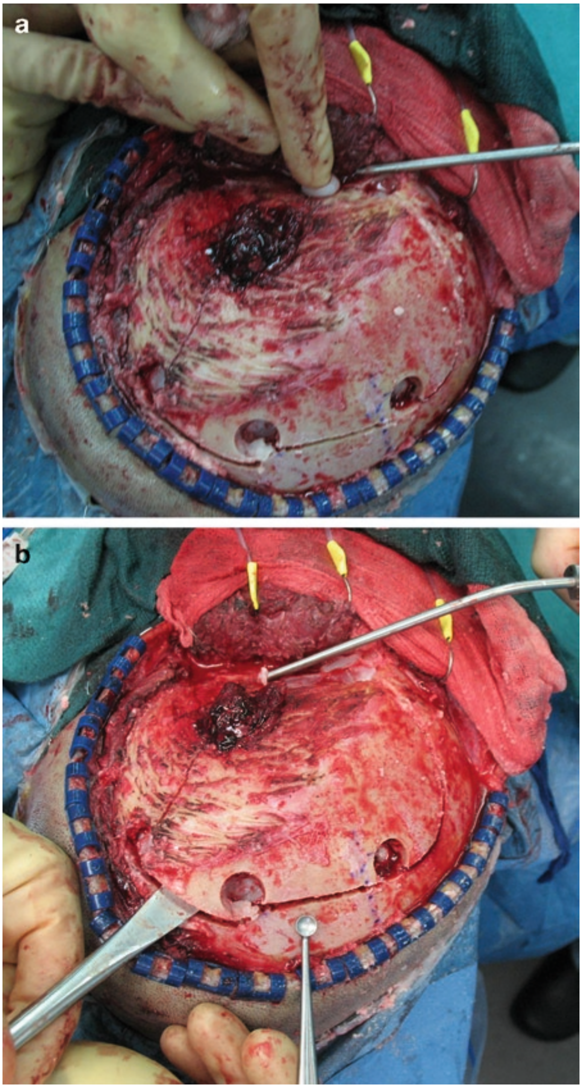

Fig. 24.10 (**a**) Completed burr holes and bone wax being applied to control bleeding from the middle meningeal artery; (**b**) connect the burr holes with a Gigli saw and then use the periosteal elevator to lift the flap and free any dural adhesions

the ICP wire from outside the scalp to inside, through the Angiocath, remove the Angiocath, and then simply pass it into the brain after first calibrating it as described in the section on placement of ICP monitors above. The location of placement is not crucial for this device, but placing it near the midline, non-mobilized portion of the scalp incision makes it easy to avoid displacement

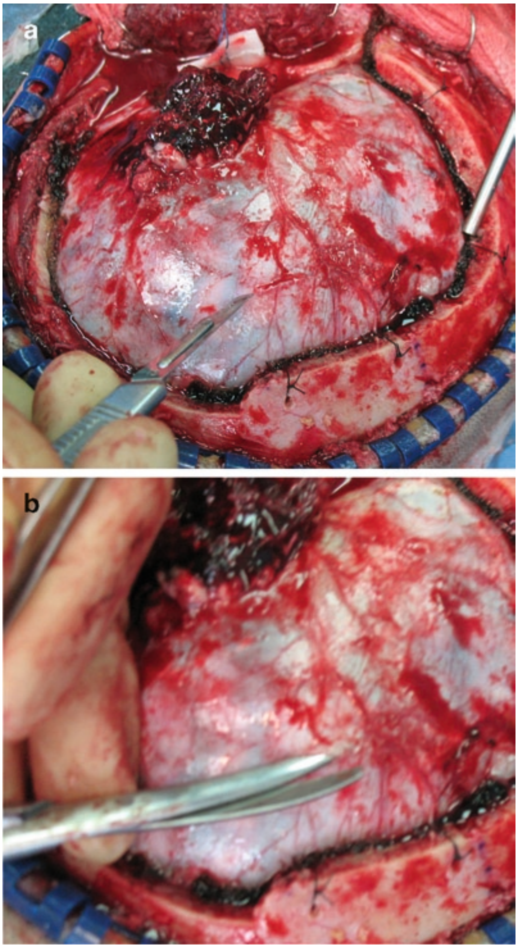

Fig. 24.11 Opening the dura. (**a**) Incise sharply with a scalpel; (**b**) open widely along the margins of the bone flap using scissors

of the device during closure. You also want to keep the location anterior to avoid the motor strip, so use the coronal suture as a landmark.

For closure, if dural substitute is available (Duragen or similar) simply lay it over the exposed brain; do not sew into place. If not available, a compressed gelfoam sheet is acceptable (Fig. 24.13). Another option is fascia lata if you have someone to harvest it in a timely fashion. Lay a 7 mm J-P drain over this dural covering, and pass out through a separate stab incision. Close the galea with interrupted inverted 2-0 Vicryl (CT-1 needle works well) and complete with surgical staples. A *loose* head wrap is then applied, and the patient maintained in the ICU with an appropriate ICP algorithm to be used for postoperative management.

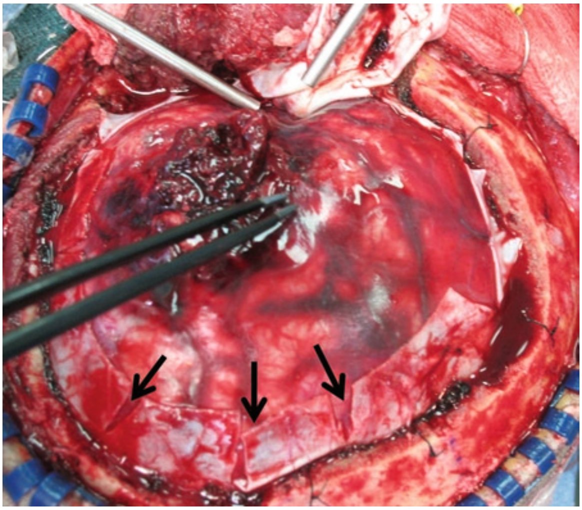

Fig. 24.12 Additional radial incisions in the dura (*arrows*) provide wide decompression. Control parenchymal bleeding with bipolar cautery and topical hemostatics

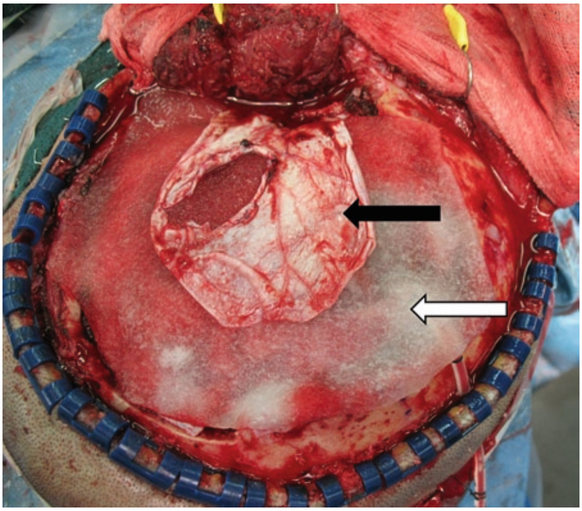

Fig. 24.13 Duraplasty prior to skin closure. A compressed gelfoam sheet (*white arrow*) is used to cover the exposed brain. The retracted dural edge (*black arrow*) is shown

Final Thoughts

Severe brain injuries are among the most devastating and unfortunately common injuries you will see in combat trauma. Know when to say “when”; if the patient has a non-survivable injury then the best thing you can do is recognize it and use your

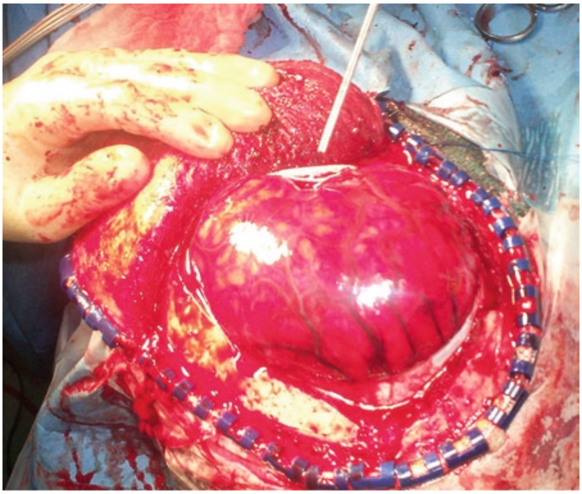

Fig. 24.14 Non-survivable brain injury with massive hematoma and cerebral edema despite decompressive craniectomy

time and resources elsewhere (Fig. 24.14). Remember that time is neurons, and the importance of what you do with the patient in that fabled "golden hour" can mean the difference between a meaningful recovery and severe disability or death. As a general surgeon in an austere environment, you should be familiar with the basic neurosurgical techniques outlined here – you never know when you might need them.

Chapter 25
Spine Injuries

Matthew Martin and Richard C. Rooney

Deployment Experience:

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BLUF Box (Bottom Line Up Front)

1. There are limited spine surgery resources in a combat theatre, so *you* are likely to be the spine surgeon.
2. With combat spinal cord injuries, what is done is done and there is little you can do acutely to improve or worsen. Therefore;
3. Do not worship at the altar of "spinal precautions"; do what you need to do to take care of the patient's injuries
4. A quick and thorough neurologic exam is key to distinguishing between complete and incomplete spinal cord injuries.
5. If there is any question about a spinal column or canal wound, wash it out and get tissue coverage.
6. Irrigation, debridement, and broad coverage of antibiotics are the key to wound management success.
7. There is little role for steroids in penetrating spine trauma, and even less in a combat theatre.
8. Treat the spine injury like a brain injury – always avoid hypotension and hypoxia.
9. Don't forget the airway! Particularly with high cervical spine injuries; delayed decompensation is common so anticipate and intubate (always before transfer).
10. Run of the mill blunt spine injuries happen in combat also – use CT scan liberally for blast and vehicular incidents.

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The expert surgeon is smarter than the algorithm.

Charles Abernathy, 1941–1994

You arrived in the theater of operations several weeks ago, and injured patients from your first mass casualty event are streaming into the ER. With the exception of the uniforms and the fact that your ER is a tent, it looks a lot like a civilian trauma event. Multiple patients arrive bleeding and moaning, almost all of them on spine boards and with cervical collars in place. One patient has multiple fragment wounds to his chest, neck, and face and is having a hard time breathing. He is bleeding around his cervical collar, but no one wants to remove it or move the patient for fear of violating "spinal precautions". Suddenly, the experienced triage physician arrives and wastes no time in removing the collar, sitting the patient upright, and assessing his neck wounds. Miraculously the patient survives with an intact spinal cord and neurologic function.

Before we begin a discussion of how to manage spine injuries in a combat setting, it is critical to understand their epidemiology and limitations of available therapies. Most will be penetrating or a combination of blunt and penetrating (blast) mechanisms. This means that most often the die has been cast long before they arrive at your facility, and either they have a neurologic injury or they don't. What you do in terms of moving them or placing them in "spinal precautions" will have little to no impact. The patient with no motor deficit but a spine that is so unstable that removing their collar and turning their head will suddenly "pith" them and result in paralysis is so rare that it should not be a consideration when you are faced with *real* and *present* injuries. This may be somewhat heretical, but do not let spinal precautions prevent you from doing what you need to do to take care of the patient.

The other important consideration is that there are almost no spinal emergencies that you will encounter in the combat setting. Almost all other injuries should take precedent in both evaluation and management, unless the spinal cord injury is impeding the airway (cervical spine) or the hemodynamics (neurogenic shock). No emergent imaging of the spine is required prior to a laparotomy or other surgery, and you can always just keep them immobilized until the spine can be safely assessed. Even if one of the rare spinal cord emergencies is encountered, such as a progressively worsening exam with a cord compression that requires surgical decompression, your job will be to stabilize and transfer the patient to a spine surgeon.

Assessing Spinal Cord Injuries

The vast majority of combat trauma is the result of explosions or gunshot wounds. Considering the fact that most of the thorax is protected by body armor, penetrating spine injuries in modern combat are quite uncommon. Most of the spine injuries tend to occur in civilians and soldiers from forces that do not routinely wear body armor. However, blasts and vehicular accidents also happen in combat zones, and these can result in the regular, run of the mill spinal column and cord injuries that you see in civilian trauma. The main difference is that you usually will not have a spine surgeon available, so *you* will be the spine expert. Fortunately, anyone with an interest can provide 99% of the critical early management that is required.

It is important to realize that recovery of neurological function after any spinal cord injury in any setting is not very good. Nevertheless, the distinction of complete and incomplete cord injury should be made as patients with incomplete injuries may derive some benefit from operative intervention such as decompressive laminectomy or removal of bone fragments that are compressing the spinal cord. Fortunately this is one area of medicine where physical examination skills are still the most important factor in the evaluation, so you should have a good basic spinal exam committed to memory. A ‘complete’ injury is an injury pattern in which there is absolutely no function below the level of the injury. An ‘incomplete’ injury is one in which there is *any* function below the level of injury. Sacral root sparing, which may allow some residual anal sphincter function or sensation or slight movement of a great toe, is an indication that the injury is incomplete and carries a better prognosis for some recovery.

Non-penetrating trauma is more likely to produce an incomplete injury. High energy penetrating trauma will more commonly produce ‘complete’ injuries. Since distinguishing between complete and incomplete spinal cord injuries is a critical task, it is important that trauma providers learn to perform a rapid yet thorough neurologic exam. The performance of such an exam is frequently overlooked in busy trauma bays. There are many different ways to do such an exam, but the main points are that in addition to global neurologic disability (Glasgow Coma Scale and pupil exam), the secondary survey of the patient should include strength testing in upper and lower extremity muscle groups and a rectal exam for tone and sensation (Fig. 25.1). Not every muscle group in the upper and lower extremities must be tested if there are no focal injuries on the extremities. For example, if the patient can flex his deltoids (C5) and extend and spread his fingers (finger flexion and intrinsic muscles of the hand, C8/T1), chances are good that everything in-between is intact. Similarly, lower extremity muscle groups can be quickly and easily tested (knee extension, L2/3, and great toe extension, L5 or ankle dorsiflexion, S1/S2) with the assumption that everything in-between is intact in the absence of any other symptoms or obvious injuries. Both upper and lower extremities and both right and left sides should be tested, as certain syndromes may cause “skip” patterns or have unilateral deficits (e.g. central cord syndrome, Brown-Sequard).

For patients who complain of a neurologic deficit or have been noted to have paralysis, this testing can become more challenging. Both knowledge of which muscle group is fired by each spinal cord level and more thorough checking for neurologic function distal to the apparent spinal cord level (including rectal exam) can help identify patients with incomplete injuries who may benefit from more urgent operative intervention. In addition, such an exam may help identify the possible injury location in order to better immobilize and prevent iatrogenic extension of the neurologic deficit. Remember that if spinal shock is present, you cannot determine whether the injury is complete or incomplete. Wait 24–48 h until the shock period is over and then do a repeat thorough evaluation.

Your exam should establish several key factors about any spinal cord injury and which any receiving spine surgeon will want to know. Both the motor and the sensory level (Fig. 25.2) of the injury should be identified and documented. The presence or

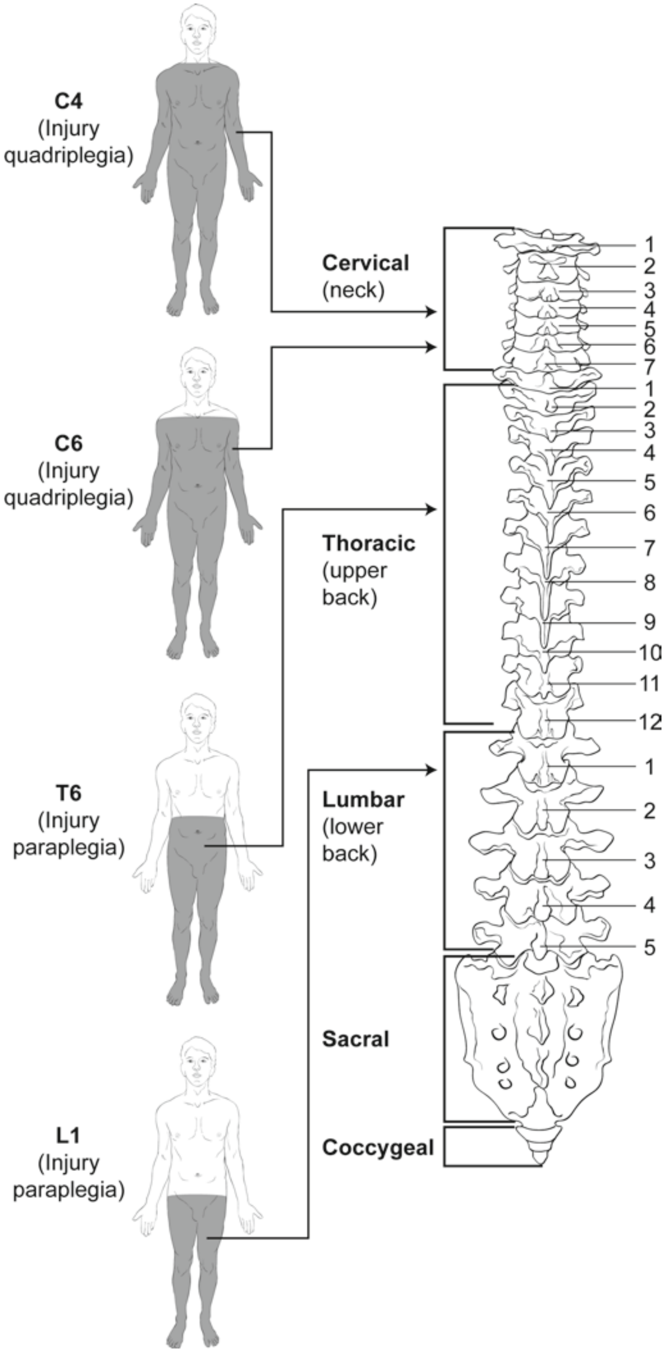


Fig. 25.1 Extent of muscle paralysis associated with different levels of spinal cord injury. Injuries above C7 will typically result in quadriplegia while injuries below C7 result in paraplegia

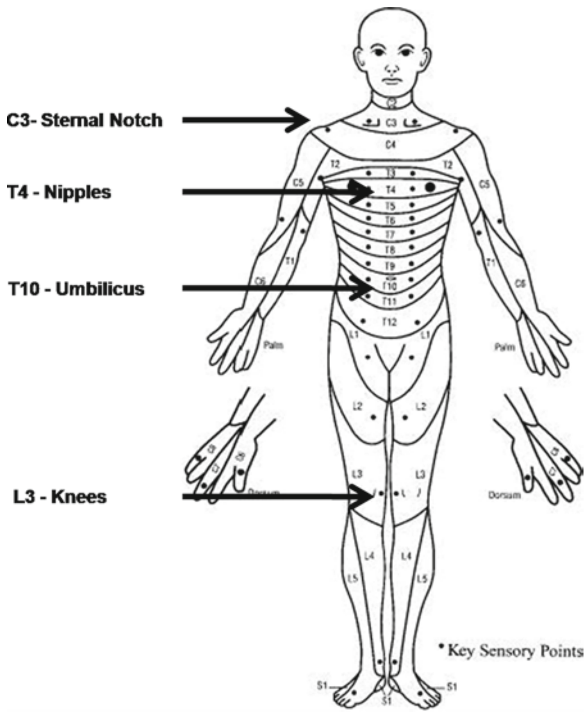


Fig. 25.2 Sensory dermatomal map and the key sensory levels with anatomic landmarks. The lowest level with intact sensation to light touch and pin prick should be identified and documented (modified with permission from Kirshblum et al., "Spinal Cord Injuries" in Physical Medicine and Rehabilitation Board Review (S. Cuccurullo editor), Demos Publishing 2004)

absence of spinal shock should be established as described below. Finally, the injury should be assessed as complete or incomplete (in the absence of spinal shock). With communication of these simple facts combined with the anatomic imaging findings (CT scan), the consulting spine surgeon can make immediate recommendations and develop the majority of the treatment plan. The evaluation and scoring sheet developed by the American Spinal Injury Association (ASIA) provides all the information you need about performing and documenting the motor and sensory exam (Fig. 25.3).

Shocking: Spinal Shock vs. Neurogenic Shock

This is a favorite board exam question, but it is surprising how many physicians continue to confuse or misunderstand these concepts. Neurogenic shock is the hemodynamic consequence of the spinal cord injury, classically characterized by bradycardia and hypotension. Cervical spine and high thoracic spine injuries are the usual culprits due to loss of sympathetic cardiac stimulation (bradycardia) and vasomotor tone in the

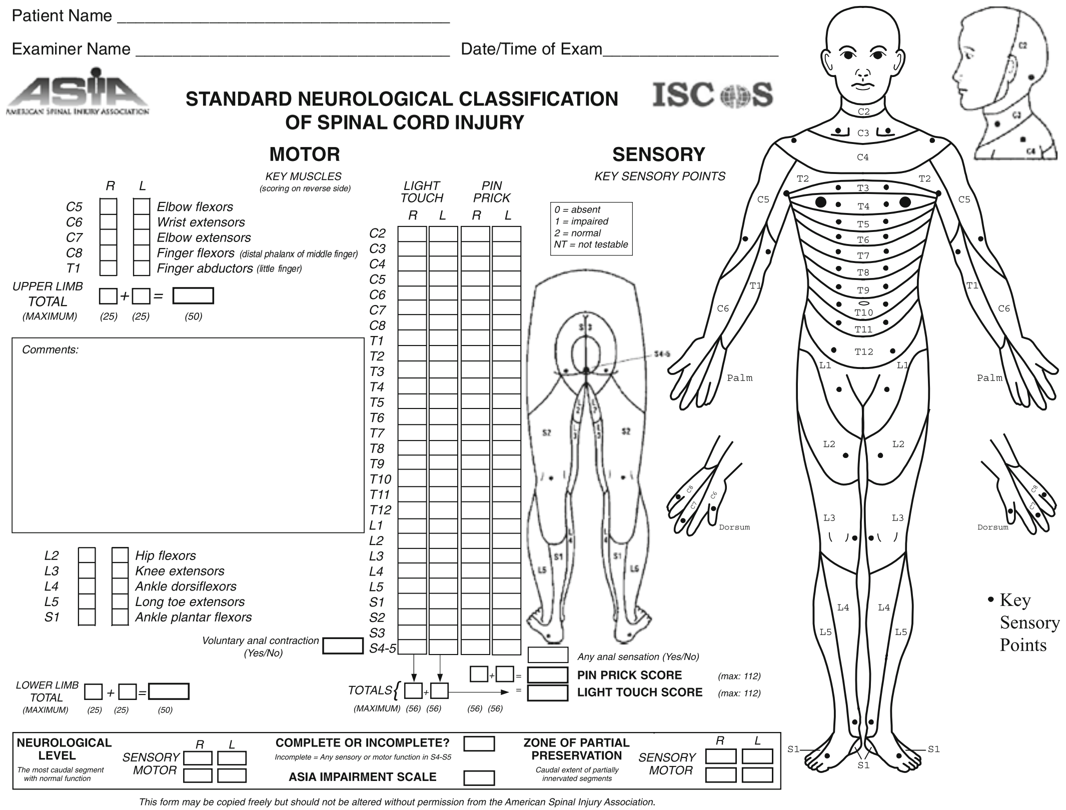


Fig. 25.3 Spinal cord injury evaluation and scoring sheet from the American Spinal Injury Association (ASIA) (reproduced with permission from Kirshblum et al., "Spinal Cord Injuries" in Physical Medicine and Rehabilitation Board Review (S. Cuccurullo editor), Demos Publishing 2004)

MUSCLE GRADING

0 total paralysis

1 palpable or visible contraction

2 active movement, full range of motion, gravity eliminated

3 active movement, full range of motion, against gravity

4 active movement, full range of motion, against gravity and provides some resistance

5 active movement, full range of motion, against gravity and provides normal resistance

5* muscle able to exert, in examiner's judgement, sufficient resistance to be considered normal if identifiable inhibiting factors were not present

NT not testable. Patient unable to reliably exert effort or muscle unavailable for testing due to factors such as immobilization, pain on effort or contracture.

ASIA IMPAIRMENT SCALE

☐ **A = Complete**: No motor or sensory function is preserved in the sacral segments S4-S5.

☐ **B = Incomplete:** Sensory but not motor function is preserved below the neurological level and includes the sacral segments S4-S5.

☐ **C = Incomplete:** Motor function is preserved below the neurological level, and more than half of key muscles below the neurological level have a muscle grade less than 3.

☐ **D = Incomplete:** Motor function is preserved below the neurological level, and at least half of key muscles below the neurological level have a muscle grade of 3 or more.

☐ **E = Normal:** Motor and sensory function are normal.

CLINICAL SYNDROMES (OPTIONAL)

☐ Central Cord
☐ Brown-Sequard
☐ Anterior Cord
☐ Conus Medullaris
☐ Cauda Equina

STEPS IN CLASSIFICATION

The following order is recommended in determining the classification of individuals with SCI.

1. Determine sensory levels for right and left sides.
2. Determine motor levels for right and left sides.
   Note: in regions where there is no myotome to test, the motor level is presumed to be the same as the sensory level.
3. Determine the single neurological level.
   This is the lowest segment where motor and sensory function is normal on both sides, and is the most cephalad of the sensory and motor levels determined in steps 1 and 2.
4. Determine whether the injury is Complete or Incomplete (sacral sparing).
   If voluntary anal contraction = **No** *AND all S4-5 sensory scores =* **0** *AND any anal sensation =* **No***, then injury is COMPLETE. Otherwise injury is incomplete.*
5. Determine ASIA Impairment Scale (AIS) Grade:

Is injury Complete? If **YES**, AIS=A Record ZPP (For ZPP record lowest dermatome or myotome on each side with some (non-zero score) preservation)

NO ↓

Is injury motor incomplete? If **NO**, AIS=B (Yes=voluntary anal contraction OR motor function more than three levels below the motor level on a given side.)

YES ↓

Are at least half of the key muscles below the (single) neurological level graded 3 or better?

NO ↓ AIS=C   YES ↓ AIS=D

If sensation and motor function is normal in all segments, AIS=E
Note: AIS E is used in follow up testing when an individual with a documented SCI has recovered normal function. If at initial testing no deficits are found, the individual is neurologically intact; the ASIA Impairment Scale does not apply.

Fig. 25.3 (continued)

lower body (hypotension). This is one situation in trauma where immediate pressor use is warranted, and the mean arterial pressure should be restored as soon as possible.

Spinal shock is the complete loss of reflexes below the level of injury, including the monosynaptic pathways. If spinal shock is present, this means that you don't yet know what the ultimate amount of recovery of function will be. You will have to wait until the spinal shock period is over. If spinal shock is not present, or it has resolved, then whatever neurologic deficits you have at that time are likely to be permanent. So for someone with paralysis, being in spinal shock is actually preferable since it leaves hope for some recovery of function. To diagnose spinal shock check the bulbocavernosus and/or cremasteric reflexes (Fig. 25.4). If they are absent, then the patient is in spinal shock, and when they return the shock period has ended.

Steroids

There is little role for steroids in a combat theatre. The associated complications are significant, the neurological recovery is questionable, and all the literature that their use is based upon is in blunt trauma with no other associated injuries. The likelihood of seeing such a patient is very, very low. Finally, the likelihood that steroids will even be available in many deployed settings is low. In general, they should not be administered unless there is some special situation that indicates some benefit could be obtained. This would primarily be a patient with a standard blunt trauma type injury with neurologic deficits, a central cord syndrome (see below), or potentially to temporize a patient with progressive neurologic deficit who requires transfer for surgical decompression.

In the rare case you do decide to administer steroids, the standard protocol is 30 mg/kg bolus of methylprednisolone followed by 5.4 mg/kg/h intravenous infusion. This is continued for 24 h if the patient is within 3 h of injury, and 48 h if the injury was between 3 and 8 h prior. There is no data to support use if the time from injury is greater than 8 h. Remember gastrointestinal prophylaxis with the steroids to prevent stress gastritis and ulceration.

Managing Closed Spine Trauma

The management of closed spine trauma is simply spine precautions (logrolling) and evacuation. Neurogenic shock should not be forgotten, but initial hypotension should be considered hemorrhage until proven otherwise. Neurogenic shock may manifest as hypotension which is poorly responsive to fluid resuscitation but responds immediately to pressor agents. Often in isolated neurogenic shock there is no associated tachycardia, the extremities may be warm and dry rather than cold and clammy, and typically the patient has a significant cervical spinal cord injury. After ensuring hypotension is not from hemorrhage, treatment involves limiting volume resuscitation and judicious use of pressors to support blood pressure. A pure vasoconstrictor such

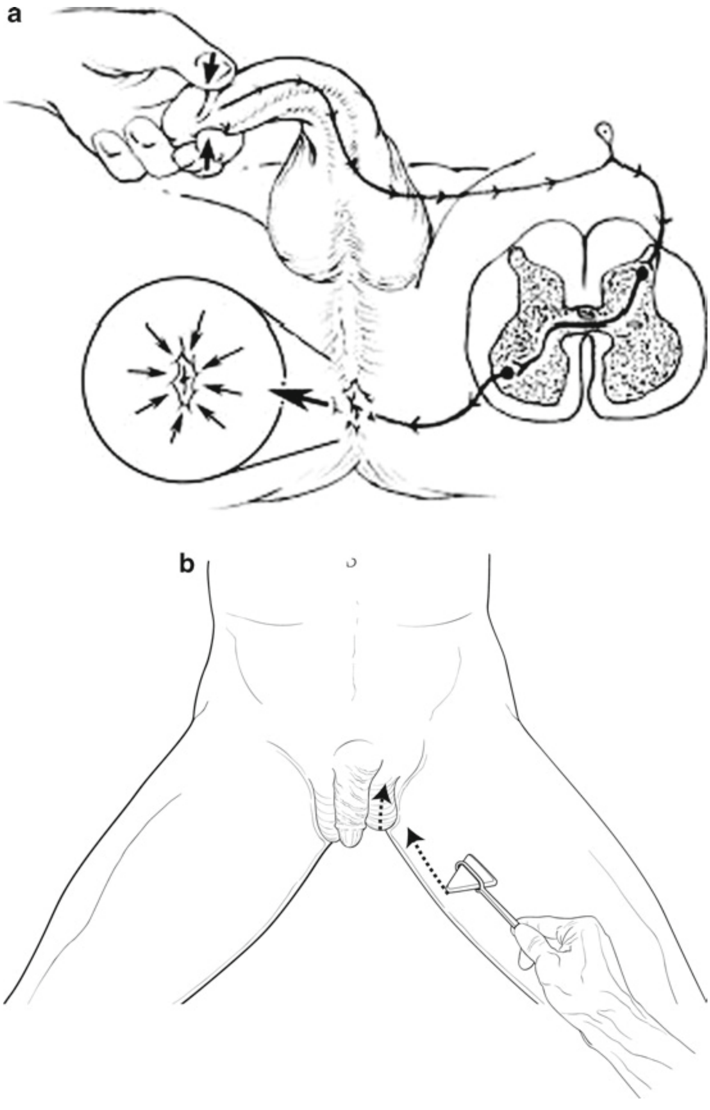


Fig. 25.4 (**a**) Bulbocavernosus reflex is tested by pulling on the shaft of the penis (or the Foley catheter) and observing for reflex contraction of the anal sphincter. (**b**) Cremasteric reflex tested by stimulation of the inner thigh which should elicit retraction of the ipsilateral testicle ((**a**) reproduced with permission from Kirshblum et al., "Spinal Cord Injuries" in Physical Medicine and Rehabilitation Board Review (S. Cuccurullo editor), Demos Publishing 2004)

as neosynephrine is often utilized, but in the multi-trauma patient or the patient with associated bradycardia, a balanced pressor such as norepinephrine is a better choice.

Keep the patient in spinal immobilization, but this does not mean lying flat and motionless. You can sit these patients up to 30° as long as they are flat, and begin participatory pulmonary toilet if they are not intubated. Ensure adequate pain control to maximize tidal volumes. Have a low threshold for nasogastric decompression as gastric ileus often accompanies spinal cord injury with paraplegia or quadriplegia. Similarly, bladder dysfunction is common and a urinary catheter should be placed if not already present. Begin management of pressure points with padding and frequent patient repositioning immediately for paralyzed patients. Do not forget the psychological and emotional aspects of these injuries, particularly in young acutely injured soldiers. Have a mental health professional and/or chaplain available to begin helping them deal with the almost uniform depression and grieving over the loss of body function that accompanies these injuries.

Managing Open Spine Trauma

The management options for open spine trauma are not much different than those for closed spine trauma, even in patients with open vertebral column fractures. The wound must be managed like any open wound. This means irrigation and debridement and early antibiotics. The choice of antibiotics is generally the same as for patients with open extremity fractures. Patients with associated intestinal injuries, particularly if those injuries communicate with the spinal column injury, may require broader coverage. The above scenario arises from a penetrating wound that goes through the spine into the abdomen or one that goes through the abdomen into the spine. Such an injury will obviously require multidisciplinary care (general surgeon plus neurosurgeon or spine surgeon).

The abdominal and the posterior wound will need to be addressed. It probably does not matter which one is done first, but you must irrigate both. The posterior wound can be addressed with the patient prone or in a lateral position. There will be no practical management strategy for dural leaks. High volume of clear fluid saturating dressings may be the first clue, or actual visualization of leaking cerebrospinal fluid during operative debridement of the wound may be noted. For most patients, pack the wound, expect significant amounts of drainage and change the dressings as needed. In patients with complete transection of the spinal cord, ligation of the thecal sac and spinal cord at the level of the injury has been used to control the leak and may be considered when there is no chance for neurologic function below the injury. More complex repairs will likely require neurosurgical or orthopedic spine expertise and may involve dural closure and perhaps diversion through drains at a higher echelon of care.

A Is for Airway

Outside of the usual issues of airway management for trauma patients which have been discussed extensively elsewhere in this book, the need for appropriate airway management is of particular importance for patients with cervical spinal cord injuries.

Most patients with high cervical spinal cord injuries will present with quadriplegia and respiratory distress or arrest and clearly require intubation. The difficult patient population is the lower cervical spine injury (C5–C7), who frequently present with no obvious respiratory distress due to the ability to continue shallow breathing. Be wary of these patients – civilian data has demonstrated that up to 50% will slowly decompensate and require a delayed emergent intervention. This can result in secondary spinal cord injury due to hypoxia and trauma from manipulation during emergent intubation attempts.

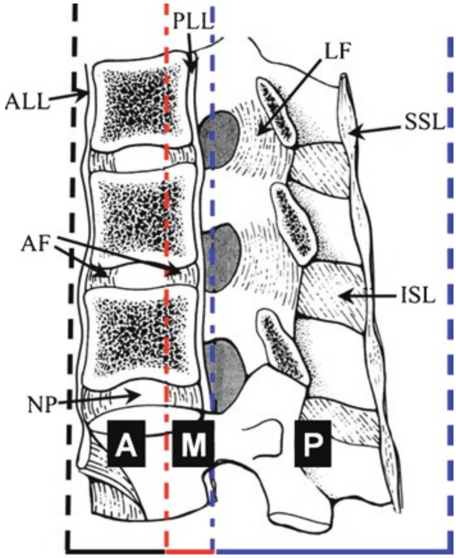
In the combat setting, you often do not have the luxury of close and prolonged observation of these patients, or you may be required to place the patient in the medical evacuation system shortly after arrival. Over a period of several hours to days the shallow breathing will result in progressive atelectasis, pulmonary consolidation or pneumonia, and finally acute hypoxic decompensation. The insidious airway collapse in this setting can be severely harmful or even fatal, and should be anticipated. Have a low threshold for intubating these patients semi-electively for the initial hospital period or prior to transfer into the medical evacuation system. Factors that should prompt you toward early intubation include higher level of injury (above C5), complete paralysis, the presence of associated injuries (particularly chest wall or intrathoracic), and low lung volumes on chest xray. If you have the capability to measure and follow vital capacity, then this may be a useful adjunct to identify the patient progressing to respiratory failure.

The final issue involving airway now that you have established the need for intubation is how to do it. Volumes have been written about the various methods for intubation in the patient with a cervical spine injury and how they impact spinal mobility. Again this comes back to the understanding that most of these injuries are already fully manifest and your method of intubation will have little to no impact. However, you should always follow good basic principles of minimizing excess spinal motion during intubation. If available, a fiberoptic intubation is safe and avoids significant spinal motion. If standard direct laryngoscopy is being performed, then have an assistant hold in-line stabilization (and cephalad traction) during the procedure. Finally, a surgical airway is always an option and may be required for patients who will require long term mechanical ventilation and/or pulmonary toilet.

Spinal Immobilization and Spinal Stability

The bony spinal column is a very sturdy structure, and it takes significant disruption of multiple structures to result in spinal instability. Blunt spinal injury is more likely to disrupt multiple areas and result in spinal instability compared to penetrating mechanisms, so isolated projectile wounds to the spine are rarely unstable. The stability of the spine primarily depends upon the integrity of three areas or columns: anterior, middle, and posterior (Fig. 25.5). The anterior column includes most of the vertebral

Fig. 25.5 Three column model of spinal body trauma. The primary ligament for each column are the anterior longitudinal ligament (ALL) for the anterior column, the posterior longitudinal ligament (PLL) for the middle column, and the ligamentum flavum/interspinous ligaments (ISL, SSL) for the posterior column (reproduced with permission from Nadalo and Moody. Lumbar Spine Trauma in Emedicine Specialties (http://emedicine.medscape.com/article/398102), Medscape 2010)



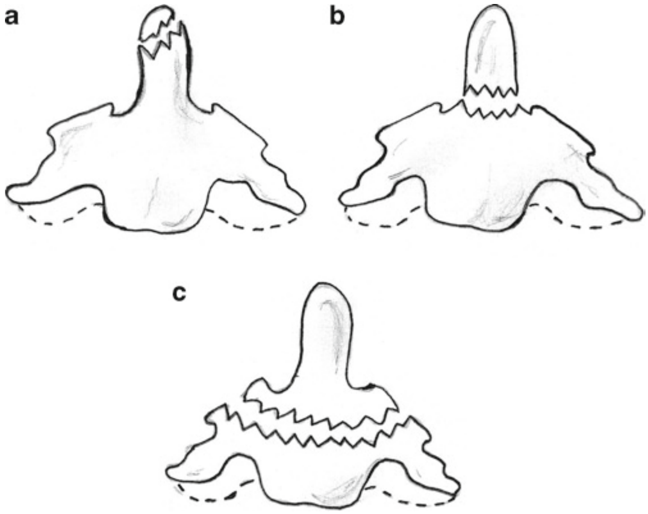


Fig. 25.6 Odontoid fractures. (**a**) Type 1 involves the tip of the odontoid process only and is typically stable but may be associated with atlantoaxial dissociation, (**b**) type II involves the base of the odontoid process, and (**c**) type III involves the body of C2 (reproduced with permission from Davenport, M. Fracture, Cervical Spine in Emedicine Emergency Medicine (http://emedicine.medscape.com/article/824380), Medscape 2009)

body and the anterior longitudinal ligament. The middle column is the posterior vertebral body and the posterior longitudinal ligament. The posterior column is the spinous process and the ligamentum flavum/interspinous ligaments. If two of these three ligamentous structures are disrupted, then the injury is likely to be unstable. Other injury patterns associated with instability are compression fractures with >50% loss of height of the vertebral body, and type II or III odontoid fractures (Fig. 25.6).

Spinal Cord Syndromes

The presentation of a traumatic spinal cord injury is usually pretty straightforward, with a dense and complete neurologic deficit below the level of injury. However, there are several spinal cord syndromes involving injuries to an isolated segment that have a much more varied and subtle presentation. These can be easily missed or mis-diagnosed if you do not do a thorough neurologic examination and consider them in your differential. Table 25.1 reviews the etiology, diagnosis, and management for the common spinal syndromes that you may encounter. For fixed and established defects, management is usually expectant and aimed at treating symptoms and pain. However, for any patient with a progressively worsening neurologic deficit, emergent consultation with a spine surgeon for possible decompression should be your first priority. Remember that the spine is just like the heart: time=neurons and they won't grow back.

No Spine Consult Needed

You may be used to consulting a spine service for any and all injuries involving the vertebral column in civilian trauma. There are multiple types of bony injuries that do not require any intervention or further evaluation, other than pain control. These include single or multiple transverse process fractures, spinous process fractures, small wedge fractures (<25% loss of height), osteophyte fractures, or chip fractures. The most common ones you will encounter are spinous process and transverse process fractures. If the neurologic exam is normal then these should all be treated with appropriate pain control, physical therapy, and a soft collar (cervical) or support belt (thoracolumbar) for comfort. You can (and should) begin immediate ambulation as tolerated based on their other injuries.

Final Comments

The impact of a spinal column or spinal cord injury in any trauma patient can range from a minor nuisance to devastating paralysis, and unfortunately these are frequently seen in combat trauma. Although as we have stated, much of the injury is done and irreversible immediately, adherence to good basic care aimed at treating the injury and preventing secondary injury may make a significant difference for the patient's ultimate functional outcome. Every deployed physician should be able

Table 25.1 Spinal cord syndromes

Syndrome	Etiology	Exam findings	Management
Central cord	Hyperflexion or extension, usually elderly with existing spinal stenosis; most common syndrome	Motor weakness of arms > legs with sacral sensory sparing	No proven benefit of prolonged immobilization Course of steroids may benefit Physical therapy and rehab Spinal decompression
Brown-Sequard (cord hemisection)	Spinal hemisection, often gunshot or knife wound	Ipsilateral loss of motor and proprioception; contralateral loss of pain and temperature sensation	Spinal stabilization if unstable Course of steroids Physical therapy
Anterior cord	Damage to anterior 2/3 of cord, usually direct injury or ischemia from anterior spinal artery injury	Loss of motor function and pain/temperature with preserved proprioception and light touch sensation	Worst prognosis with low chance of muscle recovery Physical and occupational therapy
Conus medullaris	Injury to sacral cord and lumbar nerve roots, upper lumbar (L1) fractures, disc herniation, tumors	Bowel, bladder, and sexual dysfunction with areflexia, normal leg motor function, bulbocavernosus present with high lesion	Emergent surgical decompression Course of steroids GM1 ganglioside (100 mg) IV Bowel/bladder training
Cauda equina	Injury to lumbar/sacral nerve roots, lumbar (L2 or lower) or sacral fractures, also pelvic fractures, herniated disc, tumors	Weakness or flaccid leg paralysis, high lesions spare bowel/bladder, bulbocavernosus absent	Emergent surgical decompression Course of steroids GM1 ganglioside (100 mg) IV Bowel/bladder training

to perform a quick but thorough neurologic exam, and understand the implications of significant exam findings like spinal shock. You don't have to be a fellowship trained spine surgeon to deliver high quality and effective care of combat spine injuries. Even if you can't cure them, you may mean the difference between a life of total dependence or being able to function independently.

Chapter 26
Face, Eye, and Ear Injuries

Tate L. Viehweg

Deployment Experience:

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BLUF Box (Bottom Line Up Front)

1. Obtain a definitive airway by *any* means necessary. Once the airway is obtained, *secure* it!
2. It is hard to improve upon a patent airway in a spontaneously breathing patient – don't poke the skunk unless you have to.
3. Combat wounds to the neck can be *life-threatening* and usually require neck exploration.
4. Beware of a firm, proptotic globe. This is an *emergency* requiring immediate treatment with a lateral canthotomy and cantholysis.
5. Examine *every* ear (tympanic membrane). The most common blast injury is a ruptured tympanic membrane.
6. Focus on speed and effectiveness, but don't forget basic cosmetics with wounds to the face.
7. Maxillofacial CT scans can *wait* until an initial visit to the OR in conjunction with other surgeries has stabilized the patient.
8. Explore *every* wound, and do it on the OR. Close clean wounds (rare), pack contaminated wounds (common).
9. Adapt, improvise, overcome. Seek out help and advice from your colleagues for all challenging cases.

The human body is a work of art and artistry is needed in dealing with its delicate tissues

Berkeley Moynihan, 1865–1936

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Getting Started

Injuries to the head and neck region in a combat zone are common, representing about 30% of all wounds seen in Iraq and Afghanistan. At the time of treatment, it means little to the surgeon or to the patient what the percentages are. As far as you, or the patients you are treating at the time are concerned, it is 100% of the time. Penetrating injuries are the rule of the day, but blunt trauma is not so uncommon as to disregard the possibility altogether. The most common injuries currently being seen are blast injuries, which can give you the worst of both worlds – blunt and penetrating, and sometimes with some burn thrown in for good measure. Whatever the mechanism, the principles of sound management apply and should be closely adhered to.

In the combat setting, isolated head, face, and neck injuries are relatively rare. They are usually in conjunction with other injuries which may be life-threatening. The commonly seen triad of combined severe neck, face, and brain injury seen in the combat setting has led to the development of comprehensive head and neck teams. These teams include neurosurgery, ENT, OMFS, and ophthalmology co-located at a set facility. The multi-system component of combat face injuries also provides a unique opportunity to work in concert with other surgeons; general, orthopedic, vascular, and cardiothoracic to name a few. Professionally, this is a wonderful opportunity to learn techniques from other specialties, as well as share knowledge and insight regarding surgery of the head and neck.

Avulsive and fragmentation injuries, penetrating and perforating injuries, as well as blunt trauma injuries often present unique diagnostic and surgical challenges to the head and neck surgeon (Fig. 26.1). And when I say "head and neck surgeon", I mean *you*. If you are lucky enough to be located with a trained ENT or OMFS specialist, then count your blessings. Otherwise, you are the head and neck expert and will be expected to provide competent initial management of some of the worst injuries imaginable.

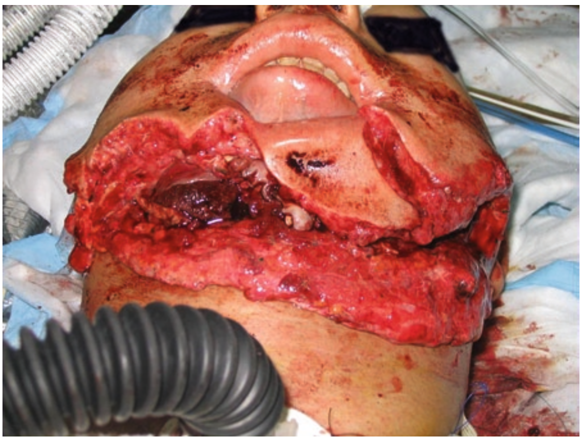

Fig. 26.1 Typical combat trauma facial injury with avulsive, fragmentation, and burn components

The Basics: Airway

You may be tired of hearing "airway first", but nothing will make you more humble than struggling with an airway in a blown apart face. If the airway is compromised, nothing else matters until a definitive airway is obtained and secured. An emergent or urgent intubation in the field may have been performed. Any patient that is intubated, either nasally or orally, is at risk for tube displacement. The endotracheal tube can quickly and easily be secured with a 2.0 nylon suture around the tube several times, and through the nasal septum in the case of a nasal intubation, or sutured or wired to teeth adjacent to the tube, using 24-gauge circumdental wiring, in the event of an oral intubation. These suturing and wiring techniques eliminate the need for circumferential tube taping techniques, and as such, are much kinder to the surrounding facial tissues in the event of severe burns. With this in mind, if the anticipated course of the patient is inclusive of several days in the ICU, repeated movement of the patient to get him or her to the next echelon of care, anticipated multiple trips to the operating room, or if severe mid-facial or pan-facial fractures are present, consideration for a tracheostomy should be given. This is a more definitive airway, with a lower risk of displacement or compromise. If a field cricothyrotomy was necessary, this should be converted to a formal tracheostomy.

Most often, you will encounter your patient in the emergency room without a definitive airway. At this time you must quickly determine the need for, and type of, airway. One of the biggest rookie mistakes is to jump to immediate intubation based on the appearance of the wound (peek and shriek) rather than an assessment of the airway. A patient that is moving air without distress and maintaining oxygenation is hard to improve upon, but can definitely be worsened by knee-jerk decisions. If the airway is stable and not at risk, the neck and facial wounds can be examined and a treatment plan formulated. If the airway is compromised in any way, the decision for intubation versus a surgical airway must be quick and definitive. Generally, an emergent or urgent intubation is sufficient to stabilize the patient for further evaluation. However, remember that chemical paralysis can turn an intact airway into a completely obstructed one. Anticipate this difficulty with intubation and have a scalpel handy for a surgical airway. Following an initial comprehensive evaluation, it may be determined that an urgent tracheostomy should be performed. This can be done in a more controlled setting in the operating room.

My technique of choice for the tracheostomy is the Bjork technique, which comprises a layered dissection through the neck in the conventional manner, with an inverted "U" incision to facilitate entry into the trachea (see Fig. 26.2). Prior to making the inverted "U" incision, I capture the anticipated flap with a 3.0 nylon suture, taking care to avoid perforating the cuff of the endotracheal tube. After removing the suture needle, the 3.0 nylon can hold anterior traction on the wall of the trachea while the incision through the tracheal rings is made. I then insert the tracheostomy tube over the flap, into the airway, and proceed. The 3.0 nylon suture is then secured to the skin below the tracheostomy with Mastisol skin adhesive and steri-strips. The placement of this suture into the tracheal flap allows for control of

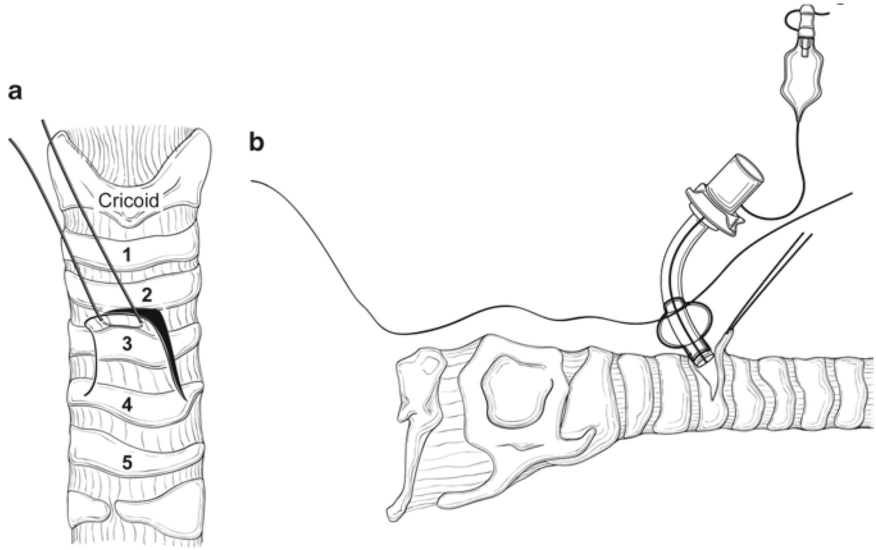

Fig. 26.2 Technique for modified Bjork flap tracheostomy

the trachea in the event the tube becomes displaced, it also prevents intubation of the pre-tracheal space in the face of edema or hemorrhage. I then suture the edges of the trach collar to the skin, and place a length of umbilical tape around the neck for further protection against displacement, unless burns or other injuries prohibit this method of securing the device.

I prefer to err on the side of a definitive surgical airway. Morbidity from a tracheostomy is relatively low, and the risk of an endotracheal tube becoming dislodged during transport en-route to a higher echelon of care via helicopter or medi-vac airplane is a greater risk than I am willing to accept for many of these patients. Penetrating injuries to the tongue with the potential for significant swelling, burn injuries to the neck and face, and inhalational injuries, should be treated aggressively with regard to a definitive surgical airway.

The Basics: Hemostasis

Following the initial evaluation of the airway, a comprehensive inspection of the head and neck is necessary, addressing the areas of active hemorrhage initially. In the single penetrating injury, hemorrhage control is straight forward; pressure, temporary dressing, surgery. The multiple penetrating injuries can be problematic from an active hemorrhage standpoint. I find that a 2.0 or 3.0 silk suture on a straight Keith needle is invaluable in temporarily closing actively hemorrhaging wounds of either a venous or arterial nature. By "pinching" the tissue with the index finger and thumb of the non-dominant hand, a quick "figure-of-eight" suture, or a horizontal mattress suture, holding the straight Keith needle in the dominant hand without a needle driver, can be quickly placed to temporarily close wounds of up to 2 or 3 cm. This hemostasis will be maintained until the wound can be definitively addressed in the operating room. In the operating room, each of these wounds should be carefully and conservatively explored where possible.

Most of the injuries to the head and neck are not life-threatening, and treatment can be delayed until the patient is stable from an airway and hemodynamic standpoint. Aside from the obvious airway concerns, injuries to the neck are the most serious. Compromise of the integrity of the great vessels of the neck can lead to rapid exsanguination and should be addressed emergently. Often, in conjunction with a general surgeon, or a vascular surgeon if one is available, unilateral or bilateral neck explorations are indicated to explore the contents of the carotid sheath, identifying and repairing injuries to the great vessels where indicated. The standard neck incision over the anterior border of the sternocleidomastoid muscle is utilized, with generally straightforward access to the anterior aspect of the carotid sheath medial to the sternocleidomastoid muscle. Injuries to the aerodigestive tract can also be identified or confirmed via this incision, and repairs made where indicated.

Once hemorrhage control has been obtained, a quick yet comprehensive and systematic examination should commence. I prefer to start at the apex of the cranium and work inferiorly, including a visual and manual inspection of the entire head and neck region.

The Eyes

Close inspection of the orbital and peri-orbital regions should be performed, with attention directed at the globes to identify foreign bodies, and injuries to the globes themselves. There is rarely an indication for you to perform an enucleation, unless it has essentially been done for you by the wound. If you suspect or diagnose an open globe, do not irrigate or put any medicinal drops into it. Cover it with a moist dressing and a hard eye patch, and transfer to an eye specialist.

In the awake and responsive patient, a quick visual acuity exam can be performed to assist with the diagnosis of ocular injury. If there is an ophthalmologist available, use him or her. If not, and you are in doubt with regard to the eye exam (i.e., foreign body within the vitreous, or a ruptured globe), a saline moistened eye patch in the interim, prior to a formal ophthalmologic exam is appropriate. Remember, the only true ophthalmologic emergency that requires immediate treatment is a hard, proptotic globe indicating an ocular compartment syndrome.

A proptotic or unusually firm globe should be an indication to further explore the need for a lateral canthotomy and cantholysis to release pressure on the globe and prevent vascular damage to the retina and optic nerve, potentially resulting in blindness. The lateral canthotomy and cantholysis is a simple procedure to perform in

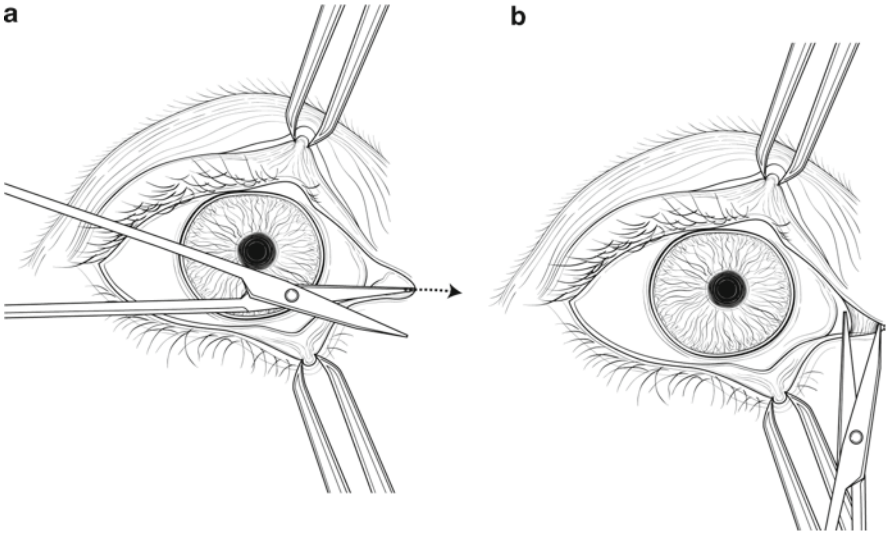

Fig. 26.3 Technique for lateral canthotomy (**a**) and cantholysis (**b**)

the emergency room, has little morbidity, and is simple to repair surgically at a later time, when appropriate (Fig. 26.3). The canthotomy is performed by holding the palpebral fissure open with the thumb and index finger of the non-dominant hand, or with the aid of an assistant, and using either a scalpel (15 or 11 blade) or a pair of fine scissors (Iris or tenotomy) in the dominant hand, to make a cut or incision immediately through the lateral canthal junction of the upper and lower eyelids. This should be full thickness (skin through conjunctiva) and extend laterally, approximately 5–6 mm. If using a scalpel, the blade should be directed laterally to prevent unintentional injury to the globe. I prefer to use scissors because they are safer and I have more control with them. Following the initial canthotomy through the skin and conjunctiva, using them closed, as a blunt instrument, I can perform the cantholysis by identifying and "strumming" the lateral canthal ligament as it attaches to the lateral orbital rim. I then release this attachment by either stripping it from the periosteum, or transecting it. This provides definitive pressure release. This is the facial equivalent of a fasciotomy in an injured extremity. This is especially important in the patient who has suffered extensive burns to the face and neck.

Imaging

Not all injuries to the head and neck region require imaging. That being said, when possible, a head and maxillofacial CT scan is invaluable when heading to the operating room. This imaging should never be obtained at the risk of placing the patient in a vulnerable position with regard to their hemodynamic picture. When in doubt, accompany the patient to the operating room with the general surgeon as they obtain hemodynamic stability. Here, you can complete the head and neck examination, address obvious needs surgically, and when necessary, obtain the CT imaging once the patient has stabilized and can tolerate the time spent in the scanner. A return trip to the operating room can then follow, if necessary.

In cases of blunt trauma, treatment can often be initiated and definitive care provided without the aid of radiographs. This is possible with an accurate manual and visual examination of the injuries, combined with knowledge of anatomy and fracture patterns. Often, in a combat setting, the temptation to give in to the civilian trauma mindset of radiographically documenting every last thing, can be time consuming and unnecessary. Trust your hands, trust your knowledge, and trust your judgment. A mobile maxilla is a Lefort I fracture. A mandibular symphysis fracture likely has a condylar component. Entrapment of the globe on superior or inferior gaze indicates an orbital floor fracture, and the inability to close the mandible as a result of a blow to the cheek is likely a zygomatic arch fracture. Radiographs, if obtained, should then only confirm what you already know.

The Soft Tissue

Many of the injuries to the face and neck are devastating from both a functional and a cosmetic standpoint. Avulsion and subsequent loss of tissue runs the spectrum from a few millimeters of missing tissue from a lip or ear, to complete loss of the entire cheekbone and orbital rim, including soft tissue. Anatomic awareness is key. Structures need to be identified and orientation needs to be maintained in order to appropriately diagnose and treat these major injuries. Macerated tissue is often encountered secondary to the destructive nature of the improvised nature of the explosions and projectiles. All soft tissue injuries that are the result of projectiles are considered contaminated. Biologic shrapnel, dirt, glass, metal, rocks, and any other form of debris imaginable are found in these wounds. Copious irrigation with or without pulsed lavage is the rule, followed by careful, detailed debridement and cleansing of the surfaces of the wounds. With tissue impregnated with macro- and micro-contamination, aggressive debridement with irrigation or pulsed lavage is essential. In many instances, revision of wound margins, including excision of charred or grossly contaminated tissue, result in clean, healthy tissue that is amenable to repair and reconstruction. Table 26.1 outlines the approach to the various facial lacerations that you may encounter.

My instruments of choice for the initial inspection and debridement of these types of wounds are a fine tonsillar hemostat and fine DeBakey forceps. By “picking” and “spreading”, wounds can be efficiently explored and debrided. The delicate nature of these two instruments enhances the tactile sensation as you encounter foreign bodies that are otherwise hidden in macerated, bloody tissue, or trapped at the base of a penetrating injury. Delicate tissue scissors, a needle-tipped Bovie

Table 26.1 Guide to laceration repair techniques by anatomic site of injury

Location	Technical points	Suture material
Scalp	Re-approximate galea, muscular aponeurosis, subcutaneous tissue, skin (generally three to four layers), sub-galeal drain (Jackson-Pratt or Blake) recommended for larger lacerations	2.0 or 3.0 vicryl for galea, 3.0 vicryl for aponeurosis and subcut, staples or 3.0 prolene for skin
Forehead	Re-approximate galea, frontalis muscle, skin (three layers of closure)	3.0 or 4.0 vicryl deep, 5.0 or 6.0 prolene skin
Eyebrow	Re-approximate inferior extension of galea, orbicularis oculi muscle, skin (three layers)	3.0 or 4.0 vicryl deep, 5.0 or 6.0 prolene skin
Eyelid	If lid margin is involved, re-approximate gray (lash) line similar to re-approximation of vermillion border on the lip. Close mucosa (conjunctiva) as necessary, and skin. Occasionally, the muscular layer needs re-approximation to provide appropriate suspension for the tarsal plate	6.0 fast absorbing or plain gut for conjunctiva, 6.0 prolene for gray line (ensure suture ends are directed superiorly to avoid corneal abrasion), 6.0 prolene for skin
Nose	Re-approximate deep skin layer overlying bone/cartilage (gently re-approximate cartilage if torn/lacerated), subcutaneous layer, skin. (two or three layers of closure depending on skin thickness)	4.0 vicryl deep, (5.0 clear nylon for cartilage suture), 5.0 prolene for thick skin, 6.0 prolene for thin skin
Ear	Re-approximate cartilage with clear suture, provide complete coverage of cartilage with skin (subcutaneous and skin layers). Apply bolster dressings as necessary	4.0 clear nylon for cartilage, 5.0 vicryl (undyed) for subcutaneous, 6.0 prolene for skin
Upper lip	Re-approximate orbicularis oris muscle first, followed by mucosal re-approximation if necessary, subcutaneous layer, skin – first suture at vermillion border to prevent visual cosmetic defect (three or four layers as indicated by injury)	3.0 or 4.0 chromic gut for mucosa, 4.0 vicryl for muscle, 5.0 vicryl for subcutaneous, 6.0 prolene for skin.
Lower lip	Re-approximate orbicularis oris muscle first, followed by mucosal re-approximation if necessary, subcutaneous layer, skin – first suture at vermillion border to prevent visual cosmetic defect (three or four layers as indicated by injury)	3.0 or 4.0 chromic gut for mucosa, 4.0 vicryl for muscle, 5.0 vicryl for subcutaneous, 6.0 prolene for skin
Cheek	Inspect Stenson's (Parotid) Duct for damage using lacrimal probes or angiocatheter, repair as indicated (specialist), re-approximate mucosa if necessary, muscular (buccinator) layer, subcutaneous layer, skin	7.0 or 8.0 nylon over silastic tubing to repair Stenson's Duct, 3.0 or 4.0 chromic gut for mucosa, 4.0 vicryl for muscle, 5.0 vicryl for subcutaneous, 6.0 prolene for skin
	Never use chromic gut on the skin of the face! It causes significant inflammatory reaction leaving permanent marks and poor cosmesis	

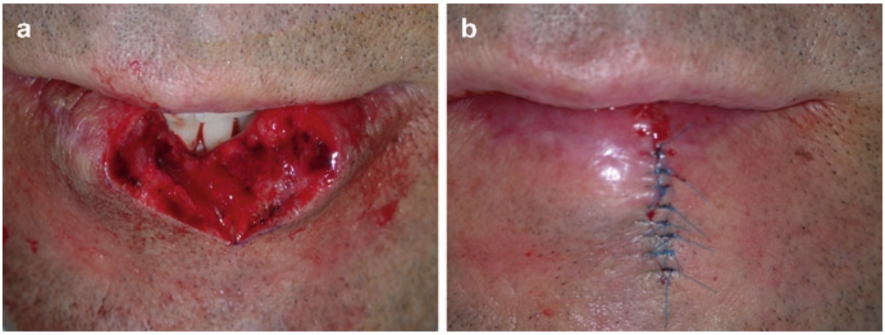

Fig. 26.4 Full thickness laceration of lower lip (**a**) requires reapproximation of orbicularis oris, alignment of vermillion border, and superficial skin closure (**b**)

electrocautery, and a 15 blade scalpel are all useful in revising wound margins in preparation for repair and reconstruction.

Lacerations to the head and neck region are a common, almost obligatory component to combat injuries. These soft tissue injuries need to be prepared for anticipated closure. Dead space needs to be eliminated with deep, resorbable sutures, or packed with iodoform or regular moistened gauze until the wound is appropriate for closure following serial wash-outs. Principles of soft tissue repair are the same for these wounds. Sound surgical techniques are critical. Re-approximation of anatomic structures, layered closure, and eversion of the skin to affect a cosmetic result, are just a few of the principles that are critical to the success of combat trauma surgery.

The vermillion border of a lacerated lip should be appropriately lined up following the re-approximation of the orbicularis oris musculature (Fig. 26.4). The margins of a lacerated eyelid or eyebrow should be addressed in much the same manner, orienting the lash line/brow line anatomically with the repair (Fig. 26.5). Avulsed portions of the ear present a surgical challenge. The ear has a tenuous blood supply, and commonly, attempted repairs fail because of this. Wedge excision of devitalized or macerated portions of the helix or anti-helix can achieve appropriate wound margins for primary closure with adjacent tissue undermining and advancement (Fig. 26.6). The lacerated or partially avulsed nose is challenging and complicated as well, and can be repaired with technique similar to the ear.

Scalp lacerations are particularly challenging in that they can lose a considerable amount of blood in a short time. This is due to the inability of vessel undergoing vasospasm to collapse upon itself because of the dense connective tissue closely adherent to the external walls of the vessel. Avulsion of a portion of the scalp is common, making primary closure difficult or impossible. Wide undermining of the galea can allow closure of what initially may appear to be a defect that will require a flap, or grafting (Fig. 26.7).

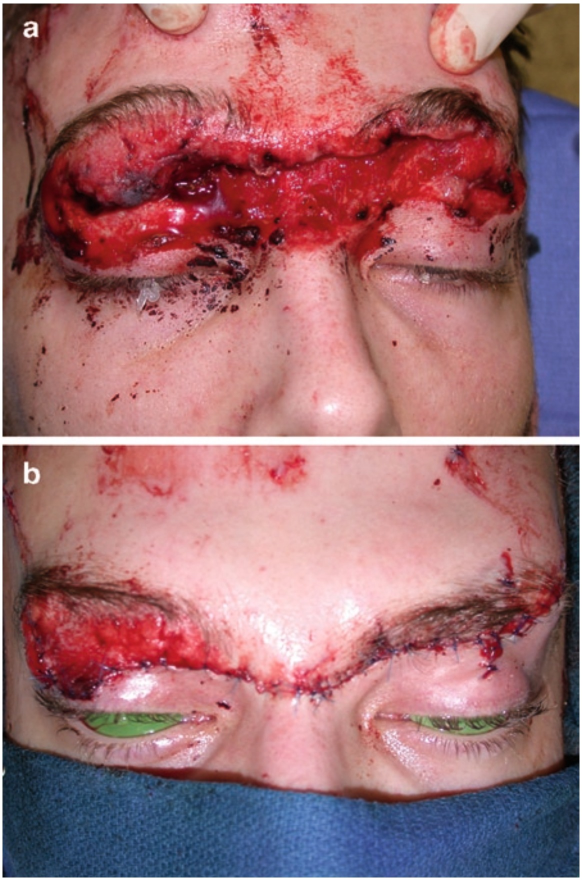

Fig. 26.5 Complex forehead laceration involving bilateral eyebrows (**a**) and after two layer repair with realignment of brow line (**b**)

The Bones

Bony step-offs in the facial skeleton, or soft depressions of the skull are usually readily apparent with a good manual examination. Avulsion of tissue, both hard and soft, can make the initial examination tricky. It is important that you maintain a high degree of anatomical orientation when evaluating injuries, as it is easy to become disoriented and incorrectly identify important structures.

With accompanying bony injury, care must be taken to correctly identify and preserve those structures that can later be utilized in the repair and reconstruction. During the inspection and debridement stage of treatment, bony fragments can be preserved to assist with repair and reconstruction. On many occasions, I have identified pieces of the zygoma or orbital rim, that I was able to clean, preserve, and utilize in the repair of the associated fractures. In one instance in particular,

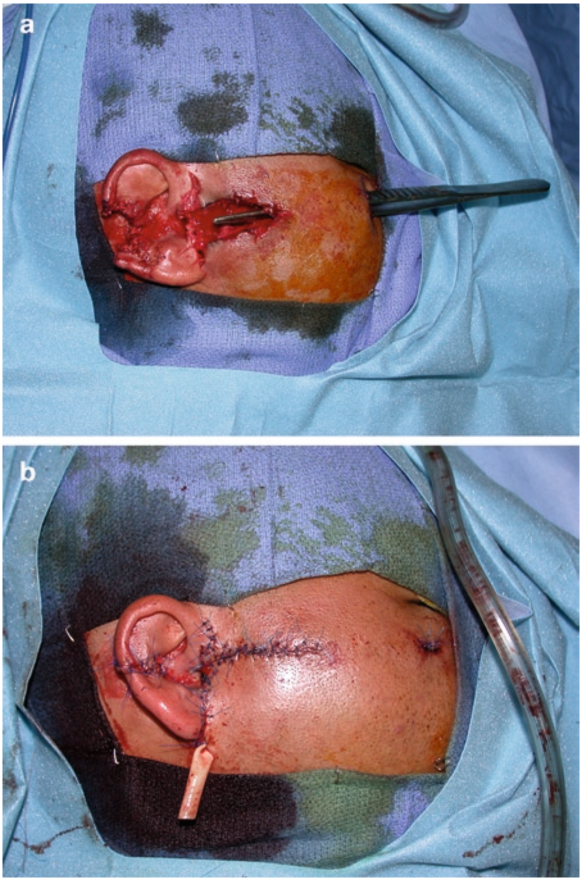

Fig. 26.6 Complex face and ear laceration with loss of helical cartilage (**a**), repaired after wedge excision of devitalized cartilage and reapproximation over penrose drain (**b**)

I found a 2 cm segment of the right infraorbital rim, including the infraorbital foramen, implanted in the right neck of the patient, as a result of a single gunshot wound to the face. I was then able to preserve the bone, and later in the case replace it and fix it with craniofacial plates and screws to facilitate reconstruction. In other cases, segments of bone can be used in other anatomic locations to affect repair.

With bony injuries, care must be taken to avoid extensive or aggressive stripping of large or small segments with adequate soft tissue pedicles, as this can potentially devitalize otherwise healthy tissue. Often times, it is a judgment call whether to maintain tissue, be it hard or soft, or sacrifice it based upon appearance or potential viability. I tend to be aggressive in debridement of wounds, unless the tissue is potentially pivotal in the eventual repair or reconstruction. If the definitive treatment won't be done for several days, there is little harm in maintaining tissue to

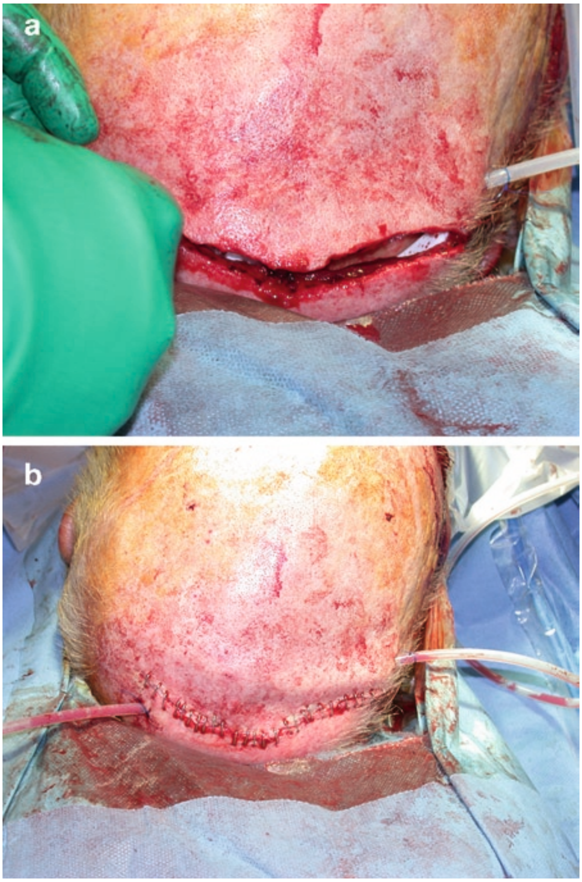

Fig. 26.7 Scalp laceration with significant tissue loss was able to be reapproximated after wide tissue undermining and interrupted closure of galea (**a**). Final closure with staples and a closed suction drain left in the subgaleal dead space (**b**)

ascertain viability. However, caution is advised, as contaminated, devitalized tissue provides a perfect environment for cultivating an infection refractory to antibiotic therapy. Deep, penetrating, or avulsive wounds that are difficult or impossible to adequately debride in one sitting should be packed with iodoform or regular moistened gauze and later returned to the operating room for further treatment, following appropriate wound debridement or washout as necessary.

Comminuted fractures of the facial skeleton should be carefully debrided, and, where appropriate, fixed with either internal or external rigid fixation. In the context of extensive contamination, or at the risk of stripping the soft tissue attachment of bony segments, internal rigid fixation should be avoided.

A suitable alternative, especially in light of open fractures not amenable to closed reduction, is rigid external fixation. Until recently, the only option for

Fig. 26.8 Monophasic external fixation for comminuted fracture of the right mandible

external fixation was the biphasic technique known widely as the Joe-Hall Morris appliance utilized to treat mandibular fractures. This option has been only marginally useful for complicated, comminuted fractures, or injuries involving avulsed segments of bone. However, devices utilizing monophasic principles of external fixation have proven useful by increasing the treatment options for severely comminuted injuries (Fig. 26.8). Success in treatment has increased with the use of these monophasic devices. Synthes CMF (Paoli, PA) manufactures an external fixation set for the mandible, however this set in generally unavailable in theater. Stryker Leibinger (Kalamazoo, MI) manufactures an external fixator set designed to treat upper extremity injuries. The Hoffman II wrist set is invaluable when utilized to treat mandibular and even mid-face fractures (Fig. 26.9). The advantage to the monophasic external fixator appliance is the ease of pin placement into the bone, followed by the ease of external framework design and application. All fittings are significantly more rigid, utilizing carbon fiber rods and precisely designed and manufactured steel attachments. Each fitting is infinitely adjustable, allowing the surgeon to make adjustments in bony fragment positioning, as well as refining the occlusal relationships of the maxilla and mandible. The advantage to these adjustments is the ability to continue the adjustments even outside of the operating room, with the patient awake. Once the final, desired position is achieved, healing can occur, and plans for future reconstruction can take place, where indicated.

External skeletal fixation of the mid-face can also be accomplished. Fixation of the zygomas is possible, as is the ability to achieve maxilla-mandibular fixation in the event of comminuted maxillary or midface fractures. This is accomplished by fixing the mandible to the mid-face utilizing the fixation screws and carbon fiber rods. A flail mandibular segment, or "bucket-handle" fracture of the mandible is of

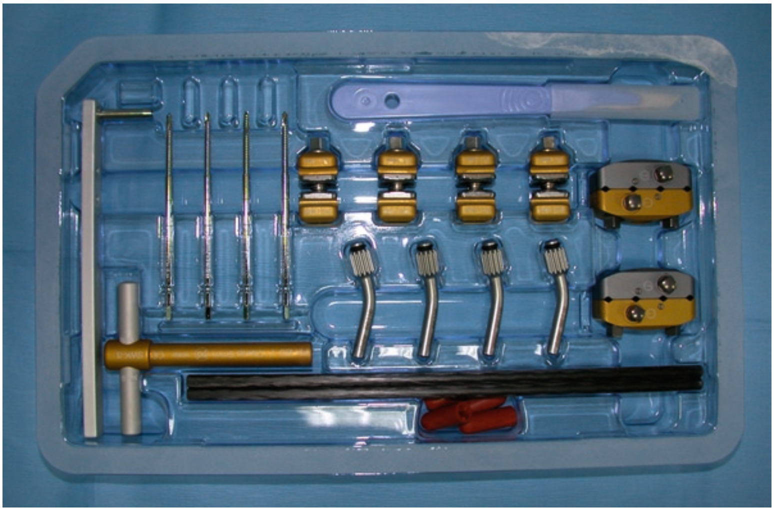

Fig. 26.9 The Hoffman II orthopedic wrist instrument set can be invaluable for managing injuries to the facial skeleton

immediate concern because of the risk to the airway. The airway should be secured, and the segment stabilized with either internal or external rigid fixation.

The Ears

Bilateral otologic examination in every patient is imperative to rule out or identify injuries to the tympanic membrane. Every ear of every combat trauma patient needs to be examined. A quick, focused otologic exam should be a part of every head and neck evaluation. Impulse noise from the explosion or gunshot causing facial injuries does in turn cause acoustic injuries. The injuries may be temporary or permanent. Hearing loss due to a perforated tympanic membrane can be easily and appropriately treated by an otolaryngologist. Approximately 80% of tympanic membrane perforations heal spontaneously. Ears with perforated tympanic membranes should be kept dry. In the presence of drainage, infection, or debris, the patient should be placed on antibiotic ear drops. The evaluation of the membrane by an otolaryngologist should consist of cleaning the ear canal, unrolling inverted mucosal edges of the perforated membrane, and placing a paper patch to cover the perforation, depending upon its size, to aid in healing and protection of the membrane and the middle ear. Surgical repair of residual perforations can be performed in a delayed fashion for up to a year from the time of injury.

Examination of the ears can further aid in diagnosis of the injuries. Bleeding from the ears, as well as the finding of hemotympanum (blood behind the membrane in the middle ear) can be indicative of a basilar skull fracture. In the comatose patient, this can be one more clue in determining the severity of a potential head injury. Otorrhea, the drainage of cerebrospinal fluid from the ear canals, is also indicative of cranial injury. Evidence of cranial injury, when identified early, in conjunction with the general surgery evaluation of the patient for other injuries, can help direct the decision making process in a more appropriate direction with regard to going directly to the operating room or obtaining radiographic studies. Unless there is strong clinical evidence of elevated intracranial pressure, a head CT, like a maxillofacial CT, can wait.

Finally

Time in the combat operating room is of the essence. It is not unusual for the facial surgeon to be asked to pack off the wound mid-surgery, take the patient to the unit intubated, and return to the operating room the next day, as the table is required for a critically injured patient with nowhere else to go. This being said, treatment of extensive injuries can often be staged in manageable increments of time to avoid risking the inability to treat someone who has life-threatening injuries.

One final note with regard to treating patients in a combat setting. There are often situations in which a given specialist is not available. For example, in the event of a depressed skull fracture, with no neurosurgeon, the combined efforts of many specialties can at least provide basic initial care to help the patient stabilize in the interim. The fracture can be elevated and the dura repaired when necessary. In the situation where a globe is ruptured and no ophthalmologist is available, an enucleation may need to be performed by someone other than an eye specialist, if access a specialist is delayed significantly. The collective knowledge of the group, a crash course in a given procedure, and sound surgical principles can produce results that can help save patient's lives and prevent undue morbidity. The austere environment has many meanings. The key is to apply good training and sound surgical principles to enhance the ability to adapt, to overcome, and to improvise, where necessary.

Chapter 27
Burn Care in the Field Hospital

Evan M. Renz

Deployment Experience:

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BLUF Box (Bottom Line Up Front)

1. Burn casualties are first and foremost, trauma patients; the burn injury is often times not immediately life threatening, whereas associated injuries may be.
2. Facial burns and suspicion of inhalation injury both warrant consideration for pre-emptive intubation.
3. Intubation of a patient is rarely emergent – there is usually time for completion of secondary survey prior to intubation.
4. Both over- and under-resuscitation may lead to morbidity in the burn casualty; avoid boluses of crystalloid whenever possible.
5. Releasing full thickness eschar (escharotomy) may be life and limb saving; fasciotomies are rarely necessary because of the burn injury itself.
6. Maximize available resources to keep the burn (trauma) patient warm.
7. Maximize every opportunity to prevent infection which represents one of the greatest threats to survival for the burn casualty.
8. Know your limitations. Burn care requires incredible time, resources, and long term care. If no local burn care is available, then you should consider treating local nationals with >50% BSA burns as expectant.

Skin is the best dressing.

Joesph Lister (1827–1912)

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This chapter is provided as both a refresher and a primer for general surgeons and other physicians who anticipate caring for burn casualties in an austere combat hospital environment. The experience level of general surgeons in the care of severely injured burn patients is widely variable, ranging from having no experience whatsoever to daily work in a burn center. The purpose of this chapter is to provide a list of key and essential management priorities which may ultimately help you improve the outcomes for severely burned patients within the limitations of your facility's resources.

The incidence of thermal injury related to military operations generally equates to less than 10% of all combat injuries. Causes of severe burns include explosions, mishaps related to fuel and munitions, and non-tactical operations such as burning of waste and debris. Recent experiences in Iraq and Afghanistan have demonstrated that thermal burns are associated with other severe injuries such as fractures, closed head injuries, and severe soft tissue loss in approximately half of the patients injured by explosive mechanisms. This fact further emphasizes the great importance of treating the burn casualty as a trauma patient, assessing for life-threatening injuries aside from the burn itself.

Recognize that the rules of engagement with respect to survivability – namely, who is declared expectant – have changed during the past two to three decades. Rapid evacuation and transport is accepted as a major factor in the survival of combat casualties on the modern battlefield. The expedited evacuation with near-seamless intensive enroute care has contributed to increased survival for many casualties, including burn patients. We have seen multiple military casualties with burns involving greater than 90% of their total body surface area (BSA) survive to return to the US, and some ultimately return home. Hence, there is no longer an absolute extent of burn injury labeled as expectant. As a general rule, remember that most burn casualties do not succumb to their immediate burn wound, and consider any burn survivable to the point of being transported stateside to receive definitive care. However, local nationals will not be able to be evacuated to a US burn center, and only rudimentary burn care is available in the far forward setting. If there is no local burn care available, then a general rule of thumb is any burn of >50% BSA should be treated as expectant with comfort measures only.

Immediate Care in the Field (Tactical Combat Casualty Care)

Even before the surgeon lays eyes on a trauma patient, he or she may be asked to provide guidance or advice in the treatment of the combat casualty in preparation for staged evacuation. Intubation of patients with facial burns is rarely required immediately following injury, except in cases where the severity of the burn constricts the soft tissue around the mouth and nose so as to restrict the airway. One common error on the part of front line medics in the initial treatment of burn casualties is the routine action of administering 2 l of crystalloid whether it is indicated or not. This action can prove harmful, especially in a patient with burns isolated to the face and/or hands. The often excessive or unneeded crystalloid fluid simply contributes to edema of the burned body area while providing little or no systemic benefit. It is reasonable to simply initiate peripheral intravascular access and start crystalloid fluids at a maintenance rate for patients with smaller size burns (less than 10% TBSA), or just heplock them until they arrive at a hospital facility. Avoid bolusing IV fluids when treating any burn patient – more fluid ends up going everywhere except where you want it to.

First-line providers are encouraged to cover the burned tissue with a clean, non-adherent dressing and avoid the use of any topical cream or ointment if it is anticipated that the patient will be evacuated rapidly. Silver nylon dressing materials are generally not indicated as an initial burn dressing unless large areas of epidermis have been lost, in which case the silver nylon dressings work well to protect the underlying dermis during transport. Blisters may be left intact during transport as they provide an initial biological protective layer. Blisters may be drained or opened when their expansion leads to severe pain, such as in the case of burns to the palms of the hands.

Although it is desirable to place a urethral catheter very early following burn injury to follow urine output, placement of a suprapubic catheter in patients with burns to the *glans* penis or deeper is rarely, if ever, indicated. It is almost always possible to place a urethral catheter in even the most severely burned casualty if basic anatomy is considered and gentle debridement is performed. A misplaced suprapubic catheter benefits no one, especially the patient.

Acute Burn Care (In the Trauma Bay)

In general, approaching the burn patient as a trauma patient is the key to successful treatment and avoidance of missed injuries. While the burn is often the most dramatic (and distracting) injury, it is not immediately life threatening. These patients should be thoroughly evaluated like any other trauma patient, and in fact they probably warrant an even more detailed search for severe associated injury. One of the reasons that we don't see more burns in the combat setting is that modern blast devices are incredibly powerful and deadly. Most victims close enough to the blast to suffer thermal burns die at the scene, so those that make it to you should be assumed to have multiple external and internal injuries.

Assessment of airway and breathing includes ensuring that full thickness eschar is not restricting ventilation. Full thickness burns to the thorax can rapidly lead to respiratory acidosis from inadequate excursion which is rapidly remedied by the performance of thoracic escharotomies along the anterior axillary lines and other regions as indicated (Fig. 27.1). Circumferential extremity burns with any evidence of impaired distal perfusion should also prompt immediate escharotomy. Escharotomy, in contrast to fasciotomy, can be readily performed at the bedside using knife and/or electrocautery (Fig. 27.2). There is little if any added morbidity since the eschar will eventually be removed. The eschar should be insensate (full thickness burn) so this can be performed with little to no sedation in the ED if necessary.

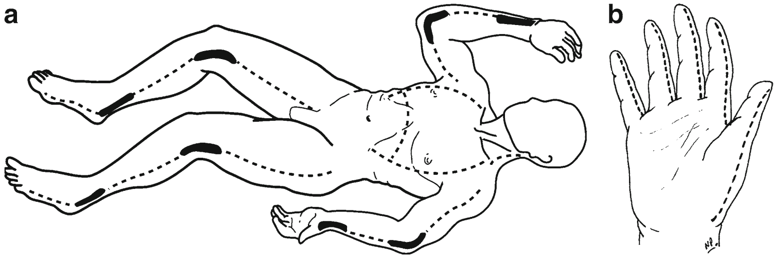

Fig. 27.1 (**a**) Standard incision lines for burn escharotomies; (**b**) Marked incisions for performing digital escharotomies. (Reprinted with permission from "Burn Injuries" in War Injuries Volume 1 (Giannou and Baldan, editors), International Committee of the Red Cross, 2009)

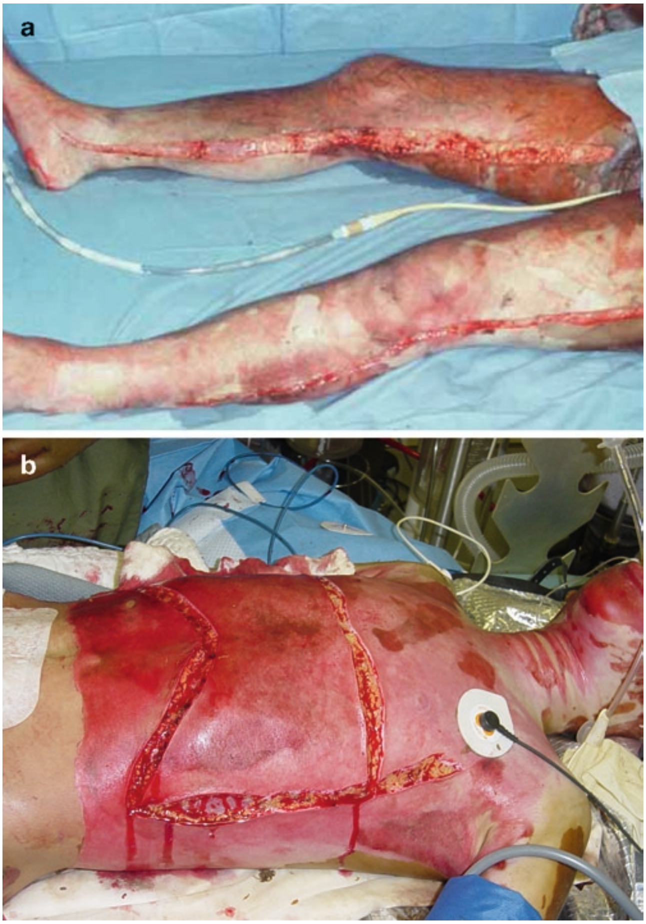

Fig. 27.2 Escharotomies for circumferential burns of (**a**) the lower extremities and (**b**) the chest wall. Note the incisions are carried down to subcutaneous fat only; fasciotomy is not required. (Panel (**a**) is Reprinted with permission from "Burn Injuries" in War Injuries Volume 1 (Giannou and Baldan, editors), International Committee of the Red Cross, 2009)

Resuscitation remains one of the most challenging aspects of burn care. The morbidity of both over-resuscitation and under-resuscitation of the burn casualty are well-described. Accurate resuscitation begins with an accurate assessment of the percentage of body surface area burned (Fig. 27.3). Remember that you should only count areas with partial or full thickness burns; superficial burns are excluded. Careful analysis of the process of burn resuscitation in the field has revealed the persistent difficulty in initiating and maintaining a consistent resuscitation across the spectrum of care and through the evacuation process. In an effort to simplify the process, Chung and colleagues developed the Rule of Ten as a tool for providers. The Rule of Ten provides an easy method of calculating the initial resuscitation fluid rate using the estimated burn size alone (utilizing the Rule of Nines). The initial fluid resuscitation rate, in milliliters per hour, is calculated by multiplying the total body surface area burned by 10 and is adjusted based upon the patient's response as measured by urine output with a target of 30–50 ml/h. This rule is for adult patients (40–80 kg). Modest increases or decreases in IV fluid rate less than 20% of the current rate are recommended to avoid unnecessary volume changes.

Rule of Ten: Multiple estimated burn size (%TBSA) × 10 to equal the *initial* rate of crystalloid resuscitation fluid.

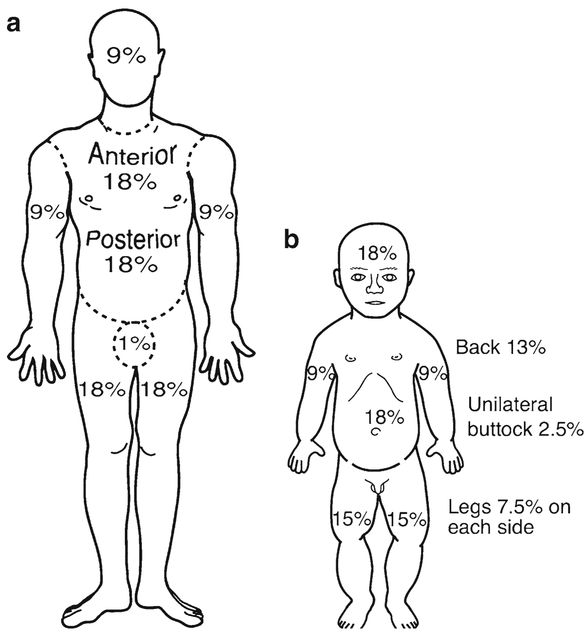

Fig. 27.3 Charts for estimating the percentage of body surface area involved with partial and full thickness burns for adults (**a**) and children (**b**). (Reprinted with permission from The Emergency War Surgery Manual (Burris et al., editors), 3rd revision 2004, Borden Institute, Washington, D.C.)

There are times when infusion with crystalloid is not adequate to achieve maintenance of adequate perfusion while avoiding the morbidities associated with hypervolemia. The addition of colloids such as 5% albumin may reduce the crystalloid requirements. In the multi-trauma patient, fresh frozen plasma (FFP) will provide very good colloid resuscitation in addition to correction of coagulopathy. If hypotension related to burn shock persists despite aggressive fluid resuscitation, the use of low dose vasopressin may be advised. Recommendations regarding these and other adjuncts to resuscitation are provided as updates to the Joint Theater Trauma System (JTTS) Clinical Practice Guidelines which are readily available on-line (Fig. 27.4).

Treatment of the burn wound initially includes cleansing the skin with an antibacterial soap such as Hibiclens®. The application of topical antimicrobials such as Silver sulfadiazine (Silvadene®) or Sulfamylon (Mafenide®) cream are effective methods of decreasing the degree of skin colonization. More recently, use of a silver nylon dressing (Silverlon®, Silverseal®) has found acceptance in the burn community due to their ease of application and documented effectiveness. One of the main advantages of using these materials in the military environment is the ability to place the wraps over multiple types of soft tissue wounds, including burns, and leave them in place with minimal maintenance during the evacuation process.

Joint Theater Trauma System Clinical Practice Guideline

APPENDIX B

JTTS Burn Resuscitation Flow Sheet **Page 1**

Date: **Initial Treatment Facility:**

Name	SSN	Pre-burn est. wt (kg)	% TBSA	Estimated fluid vol. pt should receive: 1st 8 hrs	2nd 16 hrs	Est. total 24 hrs

Date & Time of Injury

BAMC/ISR Burn Team DSN 312-429-2876

Tx Site/ Team	Hr from burn	Local Time	Crystalloid / Colloid	TOTAL	UOP	Base Deficit	BP	MAP (>55) / CVP	Pressors (Vasopressin 0.02-0.04 u/min)
	1st								
	2nd								
	3rd								
	4th								
	5th								
	6th								
	7th								
	8th								

Fig. 27.4 Joint Theater Trauma System burn flow resuscitation sheet. This document is begun at the initial point of care in the combat theater and is continued throughout the evacuation process

Burn Critical Care (The ICU Phase)

Patients with burns involving more than 20% of their total body surface area (TBSA) should be admitted to an intensive care unit (ICU) environment due the multiple organ systems affected and need for close monitoring and intervention. Airway management, pulmonary toilet, and ventilator support are routinely required, especially when the patient has sustained inhalation injury associated with the burn. Rarely, inhalation injury may be an isolated injury, but one that requires significant pulmonary support. In each of these cases, the early participation of the respiratory therapist (RT) is often key to success in survival of the burn patient.

As facial edema progresses, protection of the soft tissue of the face while simultaneously securing the airway can be challenging. The RT and bedside nurse must ensure that any securing device or tie used to secure the endotracheal tube is tight enough to eliminate excessive movement, but not so tight as to cause injury. Alternative approaches to this problem also include wiring of the ETT to a molar tooth using stainless steel wire or early performance of a tracheostomy.

Bronchoscopy should be performed as early as possible after injury to assess the airways for evidence of inhalation injury. During the early phases following injury, findings of edema, erythema, carbonaceous materials, and increased secretions are common. Later, evidence of airway sloughing, bleeding, and obstruction from mucoid plugs may be apparent. The use of nebulized heparin (5,000 units q4 h with albuterol) may help reduce the incidence of airway plugging, especially during later phases when bleeding occurs as part of the regenerative process. Pulmonary toilet is essential during all phases of treatment.

Resuscitation with crystalloid is an ongoing process for the first 24–48 h following burn injury and must be monitored carefully. Placement of an arterial catheter should be accomplished in the ICU if not previously performed in the trauma bay or operating room. The necessity for a central venous catheter is not absolute provided that redundant peripheral IV access is obtained. Tape or transparent adhesive strips do not adhere to burned skin, necessitating that all IV access devices be sewn or stapled to the patient's skin. This point is especially important prior to transport of the patient where loss of IV access in flight may become life threatening.

A nasogastric or orogastric tube should be placed early in the resuscitation phase of care to decompress the stomach, especially in the intubated patient being prepared for air evacuation. Securing the nasogastric tube with the use of cotton umbilical tape is preferred over other methods and attention should be focused on preventing further soft tissue injury from the tie itself. Gastrointestinal prophylaxis with a proton pump inhibitor is strongly recommended. The use of empiric IV antibiotics for burns is generally not recommended; however, tetanus toxoid booster is very reasonable. Conversely, the patient with multiple open wounds including open fractures and exposed joints should be treated as would any similar casualty without burns.

Abdominal compartment syndrome is of particular concern in this patient population. In addition to having severe thermal injury, many will have blunt or penetrating intra-abdominal injuries from blast effect or fragments. They also typically receive large volumes of resuscitation over the initial 48 h which increases the risk of developing a secondary abdominal compartment syndrome (ACS). ACS in the burn patient is usually not subtle; a rapid increase in ventilatory pressures coupled with decreased urine output and hypotension is typical, and is easily confirmed with measurement of the bladder pressure. The knee-jerk response is usually crash laparotomy, but before reaching for the scalpel you should consider several possibilities. Secondary compartment syndrome in these patients is often from accumulation of ascites, and this can be quickly confirmed with an ultrasound or a bedside peritoneal aspiration. Paracentesis or percutaneous drain placement will often resolve the problem without resorting to a highly morbid decompressive laparotomy. If the ACS is not due to ascites, then you need to consider the possibility that it is due to severe bowel edema (bad) or to a missed abdominal injury or newly developed abdominal catastrophe, such as dead bowel (worse). Decompressive and exploratory laparotomy should be performed but carries an overall poor prognosis.

Areas of Special Interest (Face and Hands)

Improvements in combat equipment and uniforms, particularly body armor, have decreased not only penetrating injuries to the torso, but thermal injury as well. Materials used in modern body armor are protective against thermal injury, resulting in sparing of the chest and back even when exposed to extremely high temperatures following an explosion. Likewise, increased use of ballistic eyewear has also modestly reduced the incidence of burns to the periocular region. Unfortunately, the exposed nature of the face, hands, arms and legs make them more susceptible to burns and combat burns frequently involve these areas.

When treating burns of the face, it is important to remember the priorities of trauma management, including airway protection. Although not usually immediate, intubation for airway protection may be required as fluid resuscitation is implemented. The burned tissue of the face, mouth, and tongue are prone to edema and can swell to the point of making orotracheal intubation impossible. It is therefore important to closely monitor the patient for evidence of edema and anticipate the need for intubation (or tracheostomy) before the situation becomes critical. One useful approach in patients with suspected inhalation injury is to perform an awake fiberoptic bronchoscopy and immediate intubation if significant injury is detected. Thread an appropriately sized endotracheal tube onto the bronchoscope before the procedure; if airway injury is discovered then the endotracheal tube can simply be slid down along the scope and into the trachea.

Hands burns are all too common among combat casualties, although the incidence appears to have decreased as command emphasis on glove wear has increased. Hand burns are associated with long term disability and efforts should be made to preserve hand function by minimizing edema with elevation and splinting the hands in a position of safety. Hand and digital escharotomies should be performed if necessary, and any large blisters that are limiting motion (across joint spaces) should be unroofed.

Transport of the Burn Casualty

Key factors to consider when preparing the burn casualty for evacuation include the ability of the evacuation team to provide the necessary enroute care (airway protection, ventilation, continued resuscitation, and pain control), environmental control, and soft tissue protection against further injury and infection. The timing of movement along the evacuation chain is also important to consider. If the option is available, it may be beneficial to complete the first 24 h of resuscitation prior to long-range evacuation. This ensures that this early phase of critical care is completed prior to moving the patient from the relatively controlled environment of the ICU to another staging base or aircraft. Keeping the burn casualty warm remains a priority during transport. Wrapping the patient in a custom hypothermia prevention kit or similar arrangement is strongly encouraged.

Keys To Success for the Burn Casualty Who Has Nowhere Else To Go

The US military is fortunate to boast an air evacuation system which can safely and expeditiously transport a combat casualty from almost anywhere in the world back to a stateside tertiary treatment facility within 24–48 h in most cases. The deployed trauma surgeon, however, may find him or herself facing one or more burn casualties who are not eligible for evacuation. These patients generally represent the population who are injured near a US field medical facility and present to you through one manner or another for definitive care. In the case of severely injured burn patients, the decision-making process as to whether to accept and treat the patient is relatively straightforward – you either decide to treat them or decide you are unable to treat them and either provide comfort care or send them home.

Recent US experience treating burn casualties in Iraq or Afghanistan who cannot be evacuated has led to clinical practice guidelines (CPG) citing 40–45% TBSA as the largest survivable burn size. There have been exceptions, most often involving pediatric patients or younger adults, who have survived somewhat larger burns largely due to the laudable efforts of a large team of providers who rallied their combined efforts and were not constrained due to overwhelming combat wounded during the time period. However, violating this rule usually leads to wasting of vital resources and prolonged suffering for the patient.

When the surgeon – with the support and blessing of the medical unit leadership – decides to undertake the definitive treatment of a burned casualty, the following guidelines and recommendations are offered to assist you in providing the best care possible in what may be best described as suboptimal circumstances:

1. Recognize your limitations as both a physician and as a unit. The severely burned patient, with burns often exceeding 20% or more of his or her TBSA, can represent an enormous drain on the medical facility with respect to almost all aspects of definitive surgical and medical care. The high acuity of nursing care associated with most burn patients requires increased nursing staff, especially when the staff is not accustomed to the processes involved. Supplies such as dressings, fluids, and personal protective items used for infection control will often be consumed at a higher than normal rate when caring for burn casualties. When operative intervention is initiated, blood products are frequently required coincident to each major operation. Lastly, the surgeon who commits to caring for this patient must accept that he or she is providing the best care available, even if it is not ideal.
2. Removal of the burn and coverage of the open wound is essential for survival, and the sooner the better. Preparation of the wound prior to excision includes cleansing with an antimicrobial cleanser such as Hibiclens. Excision of full thickness burns may be accomplished by serial tangential passes of a knife or bladed instrument known by several names, to include Blair, Braithwaite, Humby or Watson. This bladed instrument allows for tangential removal of the skin and the ease and efficiency in using it is directly related to the experience of the operator. Alternatively, a power dermatome may be used to excise partial thickness burns; however, this process will require an ample supply of disposable dermatome blades and the efficiency of the process will be related to the power of the dermatome.
3. Removal of full thickness burns may be accomplished with scalpel, scissors or electrocautery. This type of excision may be carried down to fascia, muscle, or even bone, depending upon the depth of injury. In extreme cases of extensive full thickness burns, amputation of the affected body part may be a necessary form of excision, especially if the injury appears to have destroyed the underlying tissue down to and including the bone. This situation is most commonly seen with high voltage electrical burns.
4. Remember that the excisional phase of the operation may result in significant blood loss. Patients should be prepared for transfusion of blood products during and following the operation. Use of pneumatic tourniquets can result in decreased intraoperative blood loss for extremities; however, the optimal depth of excision may also be more difficult to assess during the surgery as punctuate bleeding of the wound bed is a helpful marker of viability. Alternatively, the use of topical hemostatic agents (thrombin, fibrin) should be considered. The use of dilute epinephrine solution to apply to the wound bed may also help stem the tide of intraoperative bleeding. Lastly, both suture ligatures and electrocautery may be required during the case to help achieve hemostasis prior to placing the autografts.
5. Skin grafting is a surgical procedure essential to the survival of the burn patient who has deep partial or full thickness burns generally exceeding 20% TBSA (Fig. 27.5). Many surgical specialties include the basic techniques of skin grafting as part of their training programs, but few surgeons perform these as part of their routine practice. Smaller size burns may be amenable to primary excision and

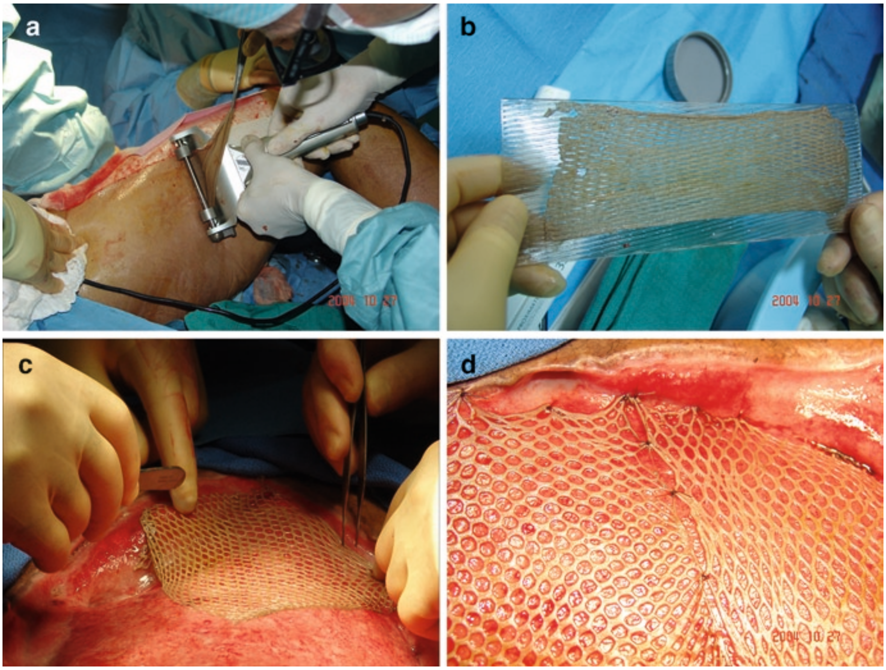

Fig. 27.5 Split-thickness skin graft procedure. The skin graft is harvested from a donor site using a power dermatome (**a**) or manually. The graft is then meshed to increase the surface area it can cover (**b**) and applied to the wound bed (**c**). Multiple sheets of graft can be secured together and to skin edges with stapled or absorbable suture (**d**)

closure of the wound, particularly when the wound allows for an elliptical excision. Larger burns and those which involve partial thickness dermal injury generally require tangential excision of the burn and coverage with a split thickness graft harvested from uninjured donor sites. Occasionally, a full thickness skin graft may be required for smaller burns in cosmetically sensitive areas (i.e. face).

6. Selection of donor sites is important when planning an operation (Fig. 27.6). The scalp is often uninjured and in most cases serves as an excellent donor site, with rapid healing and less postoperative pain than many other sites. Once the donor site heals and hair regrows, there is usually little evidence that the scalp was harvested for autograft. Other commonly used autograft donor sites include the back and thighs, each with their advantages and disadvantages. The choice of donor site dressing is often left to the preference of the surgeon. Xeroform gauze is inexpensive, is generally readily available even in remote locations, is easy to apply, and serves as an effective donor site dressing. Donor sites can generally be re-harvested in 10–14 days provided that healing is progressive.
7. Securing of split thickness autograft to the wound bed can be accomplished with the use of surgical staples, placed intermittently around the periphery of the graft as well as between the seams of adjacent grafts (Fig. 27.6). Absorbable suture can be used in the same manner. The autograft must be protected during the

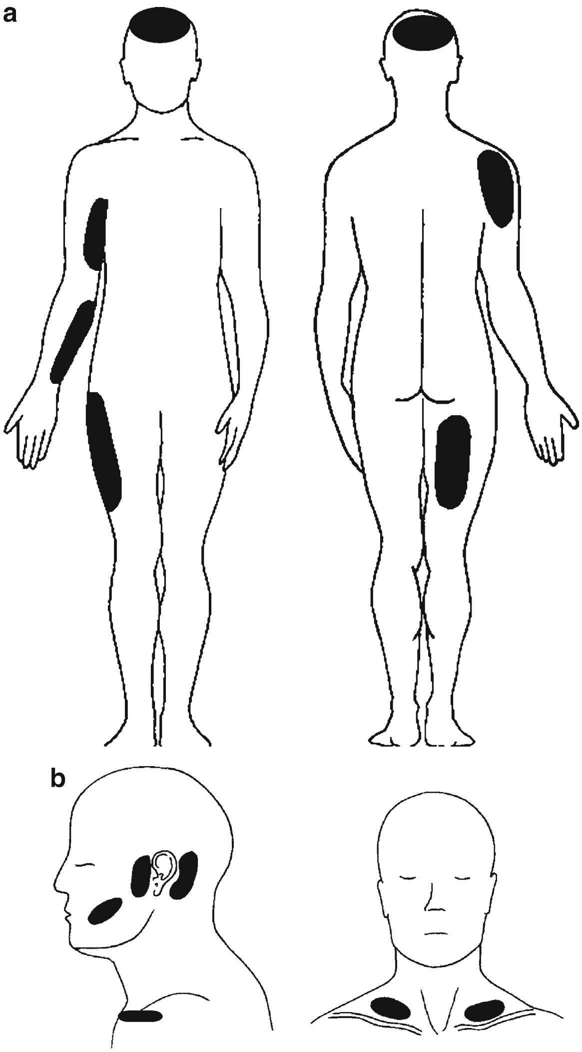

Fig. 27.6 Donor sites for split thickness skin grafts (**a**) and full thickness skin grafts (**b**). (Reprinted with permission from "Delayed Primary Closure and Skin Grafting" in War Injuries Volume 1 (Giannou and Baldan, editors), International Committee of the Red Cross, 2009)

early phases of engraftment. Dermanet® wound contact layer is a lightweight "veil" material which serves to protect the fresh graft yet allows for coverage with outer gauze or even negative pressure wound dressing. Hand and foot burns are among the most difficult to graft and dress; the availability of customized negative pressure dressings has greatly simplified the postoperative care and should be used if available (Fig. 27.7). Dressings should typically be left in place for at least 72 h prior to "revealing" and inspecting the wounds.

Fig. 27.7 Negative pressure therapy with the V.A.C. device and customized sponge (KCI USA, Incorporated, San Antonio, Texas) for partial thickness burn to the hand after excision and skin grafting

Infection is the major factor associated with mortality of the burn casualty during the sub-acute phase of hospitalization. Patient survival is often directly related to the prevention, identification, and treatment of systemic infections associated with the burn wound. Additionally, the importance of implementing strict infection control practices for burn patients has implications beyond the individual patient. Many times the infections experienced by burn patients are multi-drug resistant, thereby creating a pool of organisms which can be transferred to other patients in the hospital.

Burn centers capitalize on the importance of an interdisciplinary team to improve patient outcomes and the deployed medical treatment facility is often able to utilize the same approach to care due to the cohesive and cloistered nature of the field hospital. Crucial to the effectiveness of the multidisciplinary team is the commitment and "buy in" from the individual members of the team. Recent experience gained by deployed US military medical units has confirmed this truth as units have rallied together to provide an unprecedented level of care for many host nation civilian burn survivors who would have otherwise received little or no care.

Final Points

Thermal injury can be devastating to the patient's entire homeostatic mechanism. Thermal injuries often affect multiple organ systems simultaneously requiring a comprehensive approach to acute management. Always remember that thermal injury is a form of trauma and when sustained from an explosion is often accompanied by other severe injuries which may be more life threatening than the burn itself. Infection control is a key factor for all burn patients.

Burn casualties benefit from early evacuation to a burn center where definitive treatment including surgical critical care and rehabilitation may be initiated by a multidisciplinary team. Early communication with the burn center is encouraged and in the case of US military burn casualties this can be accomplished easily by contacting staff at the USAISR Burn Center (see below), who are readily available to provide consultation and coordination for future evacuation. Remember that the incredible work of so many dedicated professionals has resulted in a system that is able to provide a continuum of state of the art burn care for combat casualties. From the point of injury on a far-away battlefield all the way back to a stateside burn center, the outcome of these patients depends on you being a strong link in the chain of survival.

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Chapter 28
The Pediatric Patient in Wartime

Kenneth S. Azarow and Philip C. Spinella

Deployment Experience:

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Philip C. Spinella	Medical Intensivist, 31st Combat Support Hospital, Baghdad, Iraq, 2004–2005

BLUF Box (Bottom Line Up Front)

1. You will see severely injured children of all ages, and will be expected to manage them.
2. Your standard unit supplies will not include pediatric equipment, so you will have to supplement from various sources and improvise whenever possible.
3. Ensure you have the basics – pediatric peripheral and central IV catheters, endotracheal tubes, and nasogastric/urinary tubes. Almost everything else can be improvised.
4. Put all your pediatric supplies in one easily accessible and clearly marked cart or container.
5. A Broselow tape will be your best friend – have them in the ER, OR, ICU, and wards.
6. Respect the pediatric airway – misadventures during intubation are common.
7. Secure that endotracheal tube! A 1–2 cm shift can extubate an infant or child.
8. Pediatric trauma patients ARE just small adults – the primary evaluation and concerns are the same.
9. In the OR, focus on blood loss and heat loss. A few lap pads full of blood can be exsanguination in a child, and they will get cold if you don't use warming techniques.

War is the only game in which it doesn't pay to have the home court advantage.

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Just when you thought you were getting comfortable with combat trauma, an injured child rolls into your trauma bay. The pulse is 180 – can't remember if that's normal for this age or not. Don't have a small enough blood pressure cuff, but you think you might be feeling a femoral pulse. The nurses are frantically searching for IV access, and the ER docs are trying to figure out if they have a small enough endotracheal tube to intubate. Nothing can throw you off of your game like a severely injured child, and the smaller the child the larger the difficulties and anxiety. Rule number one is: You will see pediatric trauma. Rule number two should be: I will be prepared for pediatric trauma.

Throughout our nation's history, military physicians have felt the responsibility and need to care for civilian casualties. Perhaps the most innocent of these victims are children. Some of the most famous military surgeons of their time have documented exploits in caring for children. Dr Leonard Heaton took care of children that were injured as innocent bystanders at Pearl Harbor. Dr DeBakey cared for injured children in the European Theater during World War II. Current and future conflicts have been and will continue to be no different (Fig. 28.1).

Fig. 28.1 Local children greeting a United States military convoy in Iraq

In our current conflicts in Southwest and Southcentral Asia, children are more than innocent bystanders. Some are recruited as suicide bombers, and some are used as human shields. Burns are particularly prevalent and rehab facilities are non-existent. Recent data reveals that 9–15% of all inpatient beds in current combat operations are being filled by children. There are generally three routes of entry into a military care facility for children. First, they are injured as "collateral damage" from an enemy encounter or an aerial attack. Second they are used as human shields or are actually part of the enemy force. Finally they are brought as part of a humanitarian effort. This chapter will deal with critical issues concerning children with traumatic injuries in a combat setting. Nonoperative management of most pediatric trauma has become standard over the past 30 years. However, the setting and nature of wartime injuries often does not offer the combat surgeon the luxury of watching and waiting.

Intravenous Access

Unlike the adult population, attaining two peripheral IV's can be an enormous challenge in some children and central access may be technically easier. Have you best IV personnel (usually nurses and/or anesthesia providers) ready for any incoming pediatric casualties. Remember the scalp veins may be the easiest access in a baby. If this fails, then you have three options – central line, venous cutdown (usually saphenous vein), or intraosseous line. Current combat teaching is that an intraosseous placement is a safe and reliable method for access in children of all ages and should not take longer than 10 s to achieve. Intraosseous sites in infants and toddlers include the anterior tibia below the tuberosity, distal femur, proximal humerus, iliac crest, and the sternum. The anterior tibia should be your first choice in children and the technique is shown in Fig. 28.2. If that fails, then try the anterior distal femur next. There are now several excellent military kits available for both children and adults, including the EZ-IO (Vidacare Corp.) system that uses a power drill for placement (see Fig. 28.3). If an intraosseous catheter kit is not available, a strong (18 gauge) short spinal needle may be substituted. You can use this catheter as you would any central line, but it should be removed within 24–48 h.

Femoral, subclavian, or jugular percutaneous access can be safely placed and act as longer term access after the resuscitation. The use of ultrasound guidance has made central access technically easier and more reliable. In the emergency setting, the subclavian or femoral veins are easiest to access and place. However, it is true for all lines that the smaller the child the higher complication rates in the form of misplacement, pneumothorax, and hemothorax. In children less than 2 years old you should avoid the femoral area if possible due to the risk of vein obstruction or devastating injury to the femoral artery. Another good option in an emergency situation is a direct cut down, but remember that these sound easier than they are. You need good lighting, exposure, and wear magnifying loupes if you have them. Saphenous cut down in the ankle is technically easier and faster

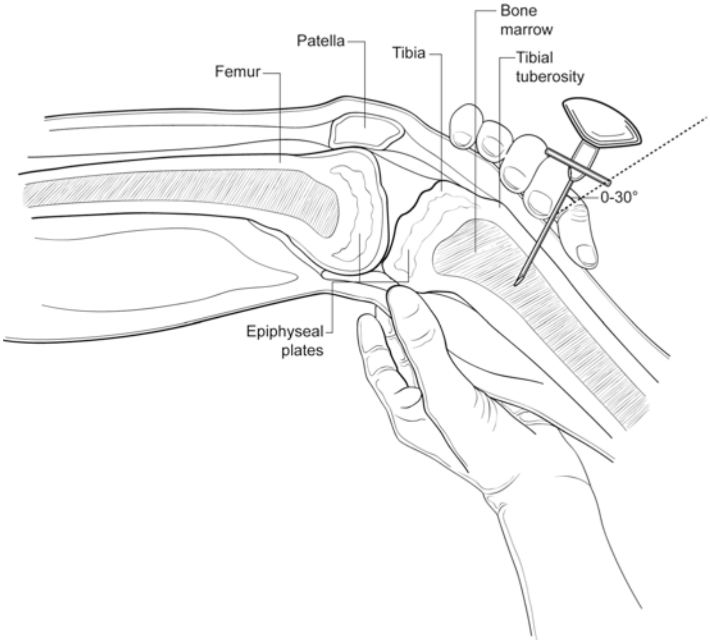
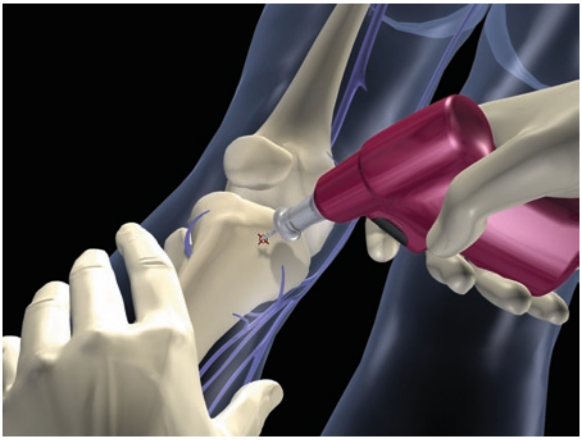


Fig. 28.2 Technique for placement of an intraosseous catheter

Fig. 28.3 Placement of the EZ-IO catheter in the anterior tibia utilizing the included power drill (image courtesy of Vidacare Corporation, San Antonio, Texas)



than in the groin in children (Fig. 28.4), but both can be effectively used. Either EJ or IJ cut downs are excellent options as long as the neck is available during the trauma resuscitation.

Technical considerations to enhance success at IV access include proper sized angiocatheters, knowing the anatomy of the venous architecture, and knowing the developmental changes that occurs throughout childhood. The use

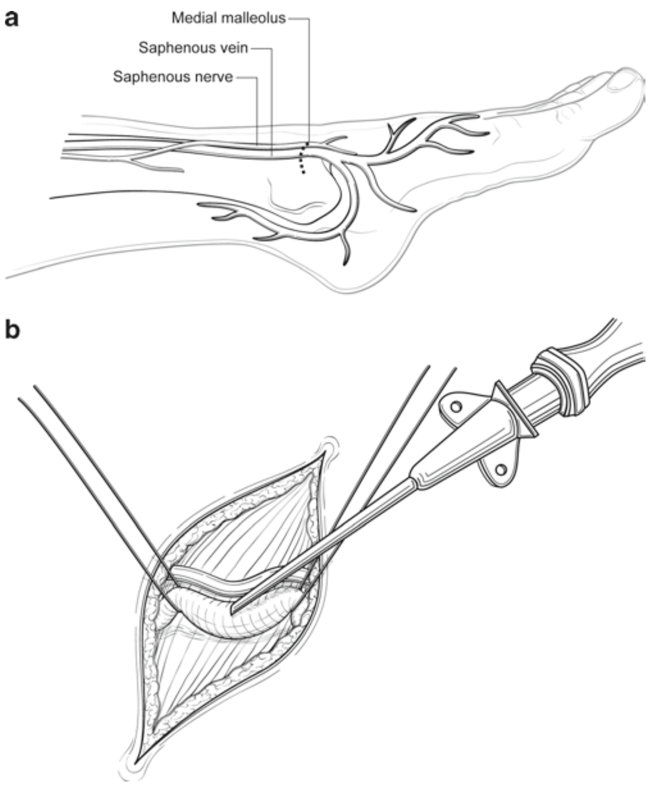


Fig. 28.4 Technique for saphenous vein cutdown

of predetermined size algorithms to determine supply sizes (Breslow© tapes) in the trauma bay are invaluable during a pediatric trauma resuscitation. Either too small (24 gauge in a child over 2 years of age) or too large (20 gauge in children under 1) will lead to failure and frustration. When in doubt, 22 gauge sized IV will be adequate for the distal saphenous vein of most toddlers and full term infants. When dealing with percutaneous central venous access there are several technical considerations to remember. The standard j-tip guide wires may not pass into the vein easily, and reversing the wire to use the straight end carries a risk of perforation. The external jugular vein can be an excellent access point, and requires only a superficial cutdown and careful placement technique. The most important advice with placement of these central lines is to use very slow and gentle motion of the needle to access the vein, otherwise you will go through the back wall. For subclavian lines, make your skin puncture site more medial than you would for an adult, and direct the needle through the space between the clavicle and first rib. You will hit the larger subclavian/jugular junction or innominate vein much more reliably than trying for the mid or distal subclavian vein (Fig. 28.5).

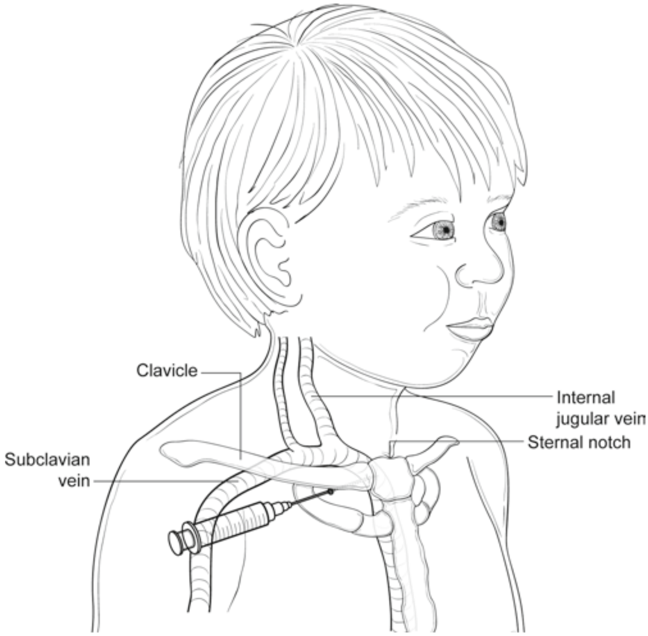


Fig. 28.5 Technique for subclavian central line placement in infants and children

Special Considerations in the ER

The overall triage, evaluation, and resuscitation priorities are the same in children as they are in adults, but there are a few major anatomic and physiologic differences that need to be appreciated. Children have large heads and tongues as well as foreshortened airways. This makes airway occlusion due to the tongue a much larger issue in the pediatric patient population. Bradycardia during intubation in children is well described, and you should either administer atropine (0.1–0.5 mg IV) during induction or have it standing by. The trachea is very short, making right mainstem intubation and inadvertent extubation very common events. Verify the correct position of the tube, and then SECURE it tightly.

While the head and airway presents the most important anatomic consideration, the most important physiologic issue concerns estimating the degree of shock. Pediatric patients will not drop their blood pressure until the last possible moment. They are able to maintain blood pressure while significantly dropping cardiac output due to an enhanced heart rate affect and the tremendous elasticity/reactivity of their peripheral vessels. Bradycardia is an ominous sign and usually indicates severe hypoxia or impeding cardiovascular collapse.

Evaluating the abdomen in a pediatric patient can be quite challenging, and supplemental imaging or exploration should be done in all trauma patients. Ultrasound images are typically excellent in children, but may be compromised by gastric or bowel distension and patient motion. Do an initial FAST exam and then decide on CT versus operation or observation. CT is the gold standard for identifying abdominal injuries and should be used liberally if there has been abdominal trauma. Discuss a protocol with your radiologist to minimize radiation exposure while still obtaining adequate images. A missed injury is much more of a concern than a theoretical increase in cancer risk decades later. Screaming children will usually have significant gastric distension which can mimic an acute abdomen. Place an NG tube and repeat your exam.

The management of pneumo and hemothorax is similar to adults, with two additional challenges. The first is selecting an appropriate sized chest tube. Very small tubes are fine if you only have air to evacuate, but larger tubes (at least 20 French) should be used to evacuate blood. The second challenge in placement is tube location. For infants and small children it is physically impossible to put your finger or even a Kelley or tonsil clamp into the pleural space to assist in directing the tube during placement. Most small tubes come with trocars to assist in placement; I recommend removing the trocar if you are not familiar and comfortable with it. If using the trocar I still recommend a cut down technique as most surgeons are far more familiar with that method than the percutaneous chest tube placement. To assist with accurate placement, pull the trocar back 1 cm so that the point is located within the tube and then perform cut down on top of the rib as normal. The trocar can then be used as a steering mechanism to guide the tube into any part of the thoracic space desired. However, it is still possible to injure the lung or mediastinal structures during tube placement.

Rapid or massive transfusion protocols are similar to those being established in adults. A 1:1:1 ratio of PRBCs to FFP to platelets is becoming standard. What is different are the volumes that are used in creating these ratios. The volumes are all weight based and calibrated in cubic centimeters not units of blood. As an estimate 80 cc/kg is considered one total blood volume in a child. Remember that while 200–400 cc blood loss in an adult is not of major concern, in a small child this can be exsanguination. **Pay attention to your blood loss, including lap sponges, and don't get behind**! Begin by administering products in boluses of 10 cc/kg for both packed red blood cells and plasma. Platelets can be administered at 10–15 cc/kg or one single donor unit per 10 kg of body weight. In the exsanguinating and coagulopathic child, Factor VIIa can be administered at a dose of 90–120 mcg/kg, with one to two repeat doses as needed.

Performing invasive or painful procedures on injured children often requires sedating agents. If there is any doubt about the airway, the safest approach is to intubate and then administer sedation as needed. In the child who does not require intubation, Ketamine is a fast acting hypnotic that provides excellent short-term sedation for procedures such as laceration repair or fracture reduction/stabilization (dose 1–1.5 mg/kg IV, 4 mg/kg IM). We recommend giving a low dose of benzodiazepine also to minimize emergence agitation. Ketamine in children is a potent sialogogue; the use of atropine or glycopyrrolate can help decrease excessive oral secretions.

Special Considerations in the OR

Preparing the trauma OR for infants and children is critical. While keeping the patient warm is essential for all trauma patients, infants are particularly susceptible to their environment. This is where the increase in surface area to body size for infants really comes into play. If not controlled for, the resultant hypothermia not only leads to coagulopathy, but will result in cardiorespiratory insufficiency due to the enormous increase in metabolic demand required by the body to maintain a normal body temperature. Bear huggers and warming devices are very useful; however often there is no substitute for keeping the room warm however uncomfortable it may be for the surgeon and OR personnel. Do not expose the child until you are ready to prep and drape.

Incisions in small infants and toddlers can be challenging. The standard midline incision for trauma laparotomy is always safe and can be utilized to achieve exposure for any part of the abdomen. However, exposure for certain areas can be improved by avoiding the midline approach. Injuries to liver, spleen, kidney and the retroperitoneum can be more easily approached via a supraumbilical transverse incision in children under 2. The downside of this incision occurs as children get older; the pelvis becomes more difficult to reach. If the nutritional status of the patient is in question, it is best to err on the side of the transverse incision as the incidence of dehiscence and evisceration is less. Appropriately sized self retaining retractors also greatly assist with exposure. Many standard self retaining systems have pediatric and infant attachments to allow the procedure to take place on any OR table.

Intraoperative management of specific injuries is very similar to that utilized in adult trauma. Solid organ salvage depends upon the physiologic circumstances and degree of injury that the patient has sustained. Never compromise patient safety in order to preserve the spleen, but a more aggressive approach to splenic preservation in children under 12–14 years old is warranted. If you are in damage control mode or the patient is unstable, take the spleen. If the patient has a severe associated brain injury, it is also better to remove the spleen rather than risk subsequent rebleeding and hypotension. Otherwise, you can proceed with a splenorrhaphy procedure based on the injury type. Fully mobilize the spleen to the midline for control and to assess the injury. The simplest, all-purpose method is to wrap the spleen with an absorbable mesh as shown in Fig. 28.6. An alternative technique is to form the mesh into a bag and use a purse string suture to close the "mouth" of the bag around the hilar vessels. If you don't have mesh, you can harvest a large square of peritoneum from the abdominal wall or use omentum to plug the laceration or wrap the spleen. Fortunately, the thicker capsule of the spleen in children allows better purchase for sutures. A similar mesh wrap technique can be applied to liver injuries after full hepatic mobilization as described for adults. Ensure that post-splenectomy vaccinations are given prior to discharge or transfer – do not wait 2 weeks or some other arbitrary interval!

You should also consider an attempt at splenic preservation with isolated injury to the pancreatic tail that requires a distal pancreatectomy. This should be limited to stable patients with no other major injuries or physiologic disturbance. The technical difficulty of this procedure is in peeling the pancreas off of the splenic vein. You will encounter multiple small branches that require clips or ligation, and take great care to avoid excess manipulation or narrowing of the splenic vein. Transect the pancreas first, and then work from proximal to distal to free it from the vein. If you encounter significant bleeding or injure the splenic vein, then just proceed with splenectomy.

The remainder of abdominal injuries should be managed similar to the adult patient. Watch your operative time and perform temporary closure as a damage

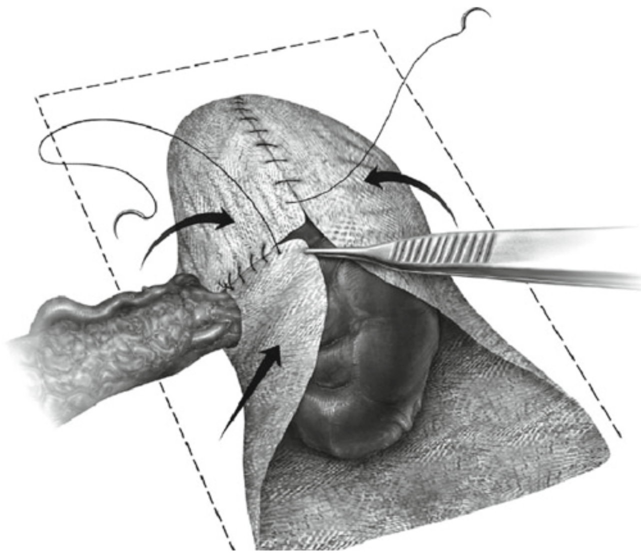


Fig. 28.6 Splenorrhaphy using absorbable mesh wrapped around the spleen after complete mobilization. Note that an adequate hole must be cut to prevent compression of the hilar vessels. (Reprinted with permission from Merchant et al., Operative Techniques in General Surgery 2008;10:7)

control measure or if a second-look operation is indicated. Monitoring for abdominal compartment syndrome is more difficult in children due to their pliable abdominal walls. Children will demonstrate minimal physiologic changes as the abdominal pressure rises until it hits a critical point, which will be followed by rapid and severe decompensation. Significantly rising abdominal pressures should prompt early intervention even without the classic signs of full blown compartment syndrome.

Special Considerations in the ICU

The principles of mechanical ventilation in children are the same that are practiced in adults. The goals are to provide an adequate amount of oxygenation and ventilation to meet the child's metabolic needs while minimizing ventilator induced lung injury. This often means the goals of oxygenation and ventilation are not to achieve "normal" partial pressures of oxygen and carbon dioxide but instead practicing permissive hypoxemia and hypercarbia. In a way this is similar to the concept of damage control surgery and as such has been referred to as damage control mechanical ventilation. In general these permissive or damage control principles allow for the pO_2 to decrease to the 50–60 Torr range as long as there is no evidence of shock on exam and allow the pCO_2 to increase to the 50–90 Torr range as long as the arterial pH remains above 7.2. Target a tidal volume of 5–7 ml/kg, enough PEEP to practice an open lung strategy and higher respiratory rates to compensate for lower tidal volumes. The only ventilator settings that are age specific are the respiratory rate and the inspiratory time. The appropriate rate may be between 30 and 40 breaths/min for neonates and infants, which requires the inspiratory time to range between 0.5 and 0.6 s. It is important to understand that there are no limits to ventilatory pressure in children. If a child needs additional PEEP or tidal volume it should be applied. If the prone position is used in a child it is extremely important to secure the airway and all vascular access when turning the child. If the child has a critical airway it is reasonable to secure the tube to the child's teeth with wires to prevent excessive movement or dislodgment.

Since the diameter of a child's airway is smaller they do become obstructed more easily. Additional pulmonary toilet measures are often needed. In addition to frequent chest physical therapy, nebulized mucolytics such as N-acetylcystine, DNA-ase, and 7.5% hypertonic saline with albuterol may be required. Another useful method of clearing an endotracheal tube of thick secretions is to use a 1:1 volume mixture of saline and bicarbonate solution to lavage and then suction the airway. The base solution is able to break up the thick secretions and allows for airway clearance with suctioning.

The transfusion approach to hemorrhagic shock is no different in children than it is in adults. Whole blood can be used to resuscitate a massively bleeding child, particularly if component therapy is not available in the combat situation. In fact, the only two prospective studies to compare whole blood to components have been performed in children and both indicated improved outcomes with whole blood. The approach to septic shock is different than in adults since the response to overwhelming infection is altered. The majority of children develop cold shock, (decreased myocardial contractility with reflexive increased systemic vascular resistance) rather than warm shock (decreased vasomotor tone). After the initial rapid volume resuscitation with crystalloids, dopamine or epinephrine at Beta agonist doses are initiated to improve contractility. For children in cold shock with adequate intravascular volume, afterload reducing agents such as dobutamine or milrinone can be used. For children who are in catecholamine resistant septic shock, hydrocortisone should be added (2–5 mg/kg/day either divided in q4–6 h dosing or as a continuous infusion).

All sedatives available can be used in children. The only agent that needs special attention is propofol. Propofol infusion syndrome causes a fatal metabolic acidosis and is also associated with cardiac dysrhythmias, renal failure, rhabdomyolysis and elevated bilirubin. It has been associated with the use of propofol in children with higher doses and when used for days. If alternative agents cannot be used for deep sedation these risks must be communicated to all staff caring for the child and frequent monitoring for acidosis is required.

The etiology of seizures in children that are evacuated to a combat support hospital after an acute injury is likely to be related to traumatic brain injury or as a consequence of hypoxic ischemic injury. Hypoglycemia, hyponatremia, and other electrolyte disturbances should always be immediately ruled out as the cause of seizure. The differential diagnosis should also include meningitis, epilepsy, hypertension and drug ingestion or overdose. A rapid acting benzodiazepine such as lorazepam (0.1 mg/kg IV) or diazepam (0.2 mg/kg IV) should be administered intravenously as a first line therapeutic agent if continued tonic clonic seizure activity persists beyond 1 min. If the seizure persists beyond several minutes, repeat dosing of rapid onset benzodiazepines is indicated. If seizures recur or persist in the minutes that follow infusion of first line agents (benzodiazepines) second line therapy is indicated. Second line agents include intravenous administration of phenytoin (18–20 mg/kg), fosphenytoin (15–20 mg/kg), or phenobarbital (15–20 mg/kg). If phenytoin is administered the rate should not exceed 1 mg/kg/min due to the risk of fatal dysrhythmias.

Humanitarian and Non-trauma Care

One of the most rewarding aspects of providing surgical care in austere environments is being able to positively impact the health of the local community. In addition, the fastest and most effective ways to win the "hearts and minds" of the local population is to care for their children. Despite what you may be told about this not being "your mission", it is an important and near universal function of the deployed physician. However, you must always strike a balance with your primary mission (military trauma care) and your capabilities. In addition, remember that although you may be able to do an incredibly complex reconstructive procedure, the required rehabilitation and follow-on care may not be available. Thus, sometimes a simpler but less optimal plan may be better than what you would typically consider the "gold standard". For example, a child is brought in with a large abdominal mass and hematuria. This is obviously a Wilm's tumor. To resect this would be easy, but if chemotherapy and appropriate follow-up are not available the surgery will be not indicated. The mortality of this child will not change and the surgery will only take away a portion of what time this child has left.

On the other hand, there are multiple interventions that you can perform that will transform the life of a child and their family. Figures 28.7 and 28.8 demonstrate several of these performed by military surgeons in the current Iraq and Afghanistan conflicts.

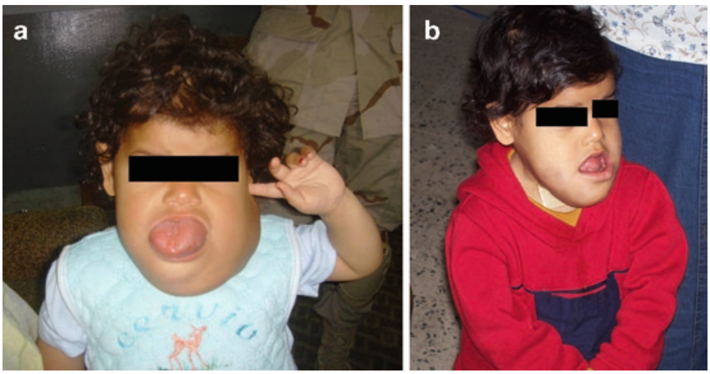


Fig. 28.7 (**a**) Iraqi child with craniofacial deformity and cystic lymphangioma of tongue requiring liquid feeds and tracheostomy. (**b**) Same child after undergoing resection of facial tumor by Air Force surgeons and subsequent hemiglossectomy by Army surgeons. She was able to begin regular diet and removal of the tracheostomy

Fig. 28.8 (**a**) Iraqi child with meningomyelocele who presented to an Air Force facility. (**b**) Same child after undergoing surgical repair by Air Force surgeons. (**c**) Child with major burns undergoing excision and skin grafting at an Air Force facility

The amount and extent of humanitarian pediatric care provided by countless military surgeons, physicians, nurses, and technicians has contributed immensely to the health of these communities and to the overall mission. This is an often under-reported and under-appreciated function of the combat physician that you should understand and prepare for. These are the cases and patients that help to make the experience of wartime medicine more bearable, and that will stay in the hearts and minds of all involved for life.

Chapter 29
The Combat ICU Team

Kurt W. Grathwohl

Deployment Experience:

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BLUF Box (Bottom Line Up Front)

1. You MUST have critical care specialists to deliver comprehensive combat trauma care.
2. Surgeons at a busy combat trauma center don't have the time to also do the critical care piece; you must have a designated and full-time ICU team.
3. Intensive care is NOT a place! It is a philosophy and application of principles that can (and should) begin in the ER and continue through to the OR and then ICU.
4. A multidisciplinary team including physicians, nurses, respiratory therapists, and other key personnel is critical to success in these complex patients.
5. Adhere to the basics, including physical exam and observation. Remarkable outcomes are possible with this approach in an austere setting.
6. Optimal ICU care includes avoiding iatrogenic complications such as resuscitation injury, abdominal compartment syndrome, acute kidney injury, and medication-related complications.
7. Adhere to simple but proven critical care interventions including daily sedation interruption, optimal pain control with minimal sedation, deep venous thrombosis prevention (mechanical methods and chemoprophylaxis), and gastric ulcer prophylaxis.
8. Routine daily checklists are how you achieve #7 in EVERY patient.
9. Infection will be your #1 killer. Adhere to hand washing, sterile technique for ALL procedures, proper line management, and judicious antibiotic use always.

Our ingenuity in developing terminology exceeds our abilities to take care of these patients once they have developed the syndrome of MOF. The solution to MOF or MODS or SIRS is prevention.

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Introduction

You have just finished your second damage control laparotomy of the day, and are nervously watching the flurry of ICU nurses around this newly arrived patient. As they connect the arterial line to the monitor you notice that the blood pressure is 80 mmHg and he's still pretty tachycardic. You order another round of blood products and some labs, but as you are writing the rest of the orders your pager alerts you to the next round of incoming wounded soldiers.

Your training in general surgery provided you with extensive experience managing critically ill surgical, postoperative, and trauma patients in the intensive care unit (ICU) environment. As a result you are uniquely qualified to manage the most critically injured patients. Your primary role far forward in the combat zone is to perform lifesaving resuscitative surgery, sometimes continuously, on multiple patients and for extended periods. Secondarily, it is expected that general surgeons participate in the peri-operative care including the critical care management of their patients. The severity of poly-trauma injuries seen on today's battlefields and subsequent use of damage control principles means that more and more complex patients will be arriving in the ICU environment and requiring incredible amounts of time and support. This support, as well as comprehensive care, continual re-evaluation, tertiary evaluation, organ specific support, thoughtful resuscitation, and adherence to standard practices to improve outcomes is best provided by general surgeons in collaboration with critical care-trained clinicians. Unfortunately, the operational tempo often precludes the presence of operating surgeons at the patients' bedside. As a result, you must rely on critical care-trained specialists to manage the most critically injured during the peri-operative period.

When Do You Need an ICU?

Military doctrine defines intensive care as a location or ward where patients requiring close observation, vital sign monitoring, or mechanical ventilation receive complex and advanced nursing care. Contrary to this definition, our experiences over the last 7 years have solidified the concept that intensive care units are not defined by location but rather by the presence of the resources (primarily personnel but also equipment) that allow the delivery of continuous critical care. Critical care should also be thought of as a system of practices that can, in certain situations, be extended to any area of the hospital. Currently, the military identifies capabilities of care by five levels or echelons. Significant variations exist both between and within the services, particularly in the concept of operations for different medical elements at level II and III. Therefore, rather than defining which level of care critical care assets are allocated, mission requirements and realities should determine what level of ICU capabilities are required. Critical care resources should be allocated to medical elements when patients require advanced resuscitation, hemodynamic assessment, continuous care, and ventilatory support for longer than 6 h. This may occur in some level II facilities (Forward Surgical Teams) but more commonly is found at most level III facilities (Combat Support Hospitals or equivalent).

Who Should Staff the ICU?

Due to improved personal protective equipment, evacuation, and first responder care, increasing numbers of patients arrive at medical treatment facilities after sustaining severe poly-trauma. They are surviving initial life-saving surgical intervention but require ongoing critical care support. Early in our experience, larger portions of patients were dying in the "ICU setting" due to potentially preventable deaths from complications associated with critical illness such as sepsis, respiratory failure, and multi-organ dysfunction. The typical forward hospital ICU mission requirements also included managing patients with cardiac, infectious, and pulmonary diseases that required advanced knowledge in medical intensive care. We also found that critical care included managing local host nation and pediatric patients for extended periods since they could not be transferred until completely medically stable. Finally, the presence of neurosurgical patients also mandated several days of ICU management to ensure medical stability prior to air evacuation or inter-hospital transport. Thus, despite the assumption that the ICU in a forward hospital will exclusively be a trauma unit, the reality is that they will need to function as a multi-disciplinary unit covering an incredibly broad number of populations and conditions.

This logistic burden, increased complexity of critical care delivery, high acuity, utilization of important resources, and numbers of potentially treatable ICU deaths makes the organizational characteristics of the ICU an important factor in potentially improving outcomes of severely injured patients. Several factors relate to improved ICU mortality, efficiency, decreased ICU/hospital length of stay, decreased medication-related adverse events, or decreased cost for intensive care unit patients. These factors include: (1) ICU organizations that include intensivists to provide timely and personal intervention; (2) intensivist involvement in administrative roles providing benchmarking, clinical research, and standardization of care; (3) the addition of critical care pharmacist; (4) reduction in critical care nursing workload; and (5) the presence of a full-time respiratory therapist dedicated to the ICU. Moreover, organizational practices within ICU's including the utilization of specific guidelines and protocols for medical and nursing care, physician credentialing for selected invasive procedures, and multidisciplinary physician team rounds and conferences also result in improved ICU-related outcomes.

Military researchers recently identified that mortality, ICU length of stay (LOS), and mechanical ventilator days were significantly reduced when the intensive care units in Iraq and Afghanistan were staffed with board-certified medical intensivists providing consultation (intensivist model). These outcomes were even better with a 30% relative reduction in mortality when the organization implemented an intensivist-directed team that included a critical care physician, rotating internist, surgeon, critical care nurses, respiratory therapist, microbiologist, radiologist, and subspecialty surgeons. In any location that requires an ICU you should employ either an intensivist or intensivist-directed team model when at all possible.

How Should the ICU Work?

Regardless if your organization chooses an intensivist or intensivist-directed team model, the intensivist's primary role should include direct patient care as well as supervision of all aspects of the critical care unit. Supervision includes the organization and delivery of critical care nursing, infection control, respiratory therapy, patient transport, and the implementation of best care and clinical practice guidelines.

Admission to the ICU is determined by the surgeon and in some circumstances after coordination with emergency medicine physicians or anesthesia providers. If time allows, communication by the admitting surgical team directly with the critical care physicians and nurses is encouraged to ensure a seamless handoff of ongoing therapies, resuscitation, surgeon's plans, and expectations. Bidirectional continuous communication between the surgeon and intensive care team is paramount during the entire patient's stay in the ICU. Direct two-way communication is of particular importance if there are disagreements regarding specific management issues or overall directions of care.

Intensivist-led multidisciplinary rounds should occur daily both in the morning and afternoon to review the patients' progress, identify emerging and resolving issues, and establish a comprehensive care plan. Daily goal sheets (Fig. 29.1) are absolutely critical to systematically ensure optimal care of critically ill patients. Do not ever assume that you can remember and track all of this information in such a complex environment. And even if you can, others cannot.

Ultimately the surgeon remains the "captain of the ship" for most trauma patients while the intensivist is more like the cruise director. Evacuation and/or discharge from the ICU are determined by the surgeon although some circumstances require consultation with the intensivist or other members of the critical care team. As this relationship matures and strengthens, the intensivist typically assumes more responsibility for primary decision making and guiding therapy. This is of particular importance during times of high volume or mass casualty situations, where the surgeons will be otherwise occupied and the care of the ICU patients will fall entirely on the intensivist and his or her team.

How Do You Set Up a Forward ICU and What Pieces of Equipment/Supplies Do I Need?

The most important concept when setting up a forward ICU is to identify and allocate the appropriate types and numbers of personnel to manage critically injured/ill patients. The forward ICU can be a building, room, tent, iso-shelter, bed, cot, or piece of ground that you allocate with the appropriate critical care personnel. Figures 29.2 and 29.3 demonstrate the wide variability seen in location of a far-forward ICU. Simply grouping the most critically injured/ill patients in close proximity improves the ability of limited numbers of personnel to provide critical care support.

DAILY GOAL SHEET TO BE FILLED OUT BY ALL TEAMS FOR ALL PATIENTS IN THE ICU.
ICU QA/QI.

ICU Room# Code Status: Allergies:

Date: __________ Primary Service: ICU GS/Trauma CT Vascular Other:
Attending: __________________

Is the Universal Consent Signed?	**(Consent?)**	Y	N	NA
Have all of the bedside nurse questions been addressed?	**(NQ's?)**	Y	N	
Have all the patient's questions been addressed?	**(PQ's?)**	Y	N	
Is the patient on a ventilator?	**(Ventilator?)**	Y	N	Trach
Spontaneous Breathing Trial Performed?	**(SBT?)**	Y	N	NA
Sedation holiday performed?	**(DSH?)**	Y	N	NA
Is the Head of the bed >30 degrees?	**(HOB >30?)**	Y	N	NA
Is Oral Care being performed every six hours?	**(Oral Care?)**	Y	N	NA
Is the patient receiving PUD prophylaxis?	**(PUD?)**	Y	N	NA
Is the patient receiving DVT prophylaxis?	**(DVT?)**	Y	N	NA
Are day/night cycles adhered to?	**(Day/Night?)**	Y	N	NA
Can the patient be mobilized?	**(PT/OT?)**	Y	N	NA
Have Restraints been ordered if necessary?	**(Restraints?)**	Y	N	NA
Can any central lines or other devices be removed?	**(Lines Out?)**	Y	N	NA

If so, which one(s): ______________________________

Was the ECG Reviewed?	**(ECG?)**	Y	N	NA
Was nutrition addressed?	**(Nutrition?)**	Y	N	NA
Was a bowel regimen addressed?	**(BMs?)**	Y	N	NA
Was skin care/pressure ulceration addressed?	**(Skin?)**	Y	N	NA
Were the medications reviewed?	**(Meds?)**	Y	N	NA

Starting: ______________________________

Stopping: ______________________________

Daily I/O goal is: Positive Negative Even

What is the patient's greatest safety risk??
____

What is being done for the patient that cannot be done in a lower level of care?
- Technology (i.e. ventilator) ☐
- Monitoring (frequency or invasiveness) ☐
- Interventions (intensity) ☐

Today's Big 3 Goals:

1)______________________________

2)______________________________

3)______________________________

Name:__________
Reg # __________
SSN:__________
Enter info or place pt sticker here

Fig. 29.1 Sample daily goal sheet that should be used every day for every ICU patient. The details of the sheet can be adapted to each unique setting in the deployed environment

You will not have all of the equipment and technological gadgets that are increasingly common in modern civilian ICU environments. This is good news since the equipment available in most U.S. military level II and III facilities are limited to the designated table of organization and equipment (TOE) for that unit. Each piece of equipment comes at the price of weight and cube, which challenges

Fig. 29.2 A front-line ICU is established in a very austere environment by simply grouping critically injured patients together in proximity to the available highest level of provider care and equipment

the logistics system. Additionally, many pieces of equipment require battery or generator power and are prone to malfunction or breakdown. You should therefore be prepared to manage ICU patients with only your head, eyes, ears, nose, and bare hands. Nevertheless, military planners have decided that essential pieces of equipment for an ICU include multi-parameter monitors capable of handling pressure transducers and capnography, transport ventilators, multi-channel infusion devices, portable suction, and point of care laboratory testing (i-STAT, Abbott Laboratories, Abbott Park, IL). Portable and handheld ultrasound devices are also becoming important diagnostic tools for far-forward ICU's, and should be integrated into your ICU practice. If you are not comfortable with basic ultrasound examinations, you MUST familiarize yourself before or during deployment. Your colleagues, particularly in Emergency Medicine and Radiology, will be valuable assets in helping you become ultrasound competent. All of the above listed ICU equipment is designed to run for several hours on battery power as your standard power sources may be lacking or unreliable.

Despite efforts to standardize equipment between and within services, medical units continue to field and maintain different pieces of equipment. Some pieces of equipment can have remarkably different capabilities. Examples are the portable transport ventilators with many units fielding the Uni-Vent® Eagle 754™ (Impact Instrumentation, West Caldwell, NJ) or the Pulmonetic LTV® 1000 (Viasys,

Fig. 29.3 A more "mature" Intensive Care Unit established in a fixed structure at the Combat Support Hospital level (Ibn Sina Hospital, Baghdad, Iraq)

Minneapolis, MN). In addition, some units have individually purchased modern intensive care ventilators with unconventional ventilator modes to manage the most challenging patients. A discussion regarding each piece of equipment is beyond the scope of this chapter; however, deploying surgeons should become familiar with the capabilities and function of equipment in their unit's TOE. Surgeons should prepare contingency plans to provide critical support without all the fancy gadgets should they malfunction or become unavailable. After arriving at your new location in a forward environment, your second stop (after the OR) should be an inspection and inventory of your ICU equipment and capabilities.

The large logistical burden of oxygen deserves mention since oxygen is an important aspect of managing critically injured/ill patients. Unfortunately, all oxygen-generating systems are unreliable and as a result we relied on oxygen conservation and pressurized oxygen cylinders – sometimes transported hundreds and thousands of miles. Oxygen conservation requires both proper patient selection to receive supplemental oxygen and an understanding of the differences between internal compressor ventilators and those requiring high pressure gas for operation. Most internal compressor ventilators can be configured to deliver high levels of oxygen concentration (66–74%) with low flow oxygen to meet most patients' needs.

The supplies available in the far-forward ICU are standardized with a surprising wide spectrum of medications including anti-eptileptics, antibiotics, sedatives, analgesics, vasoactive medications, anticoagulants, anti-arrhythmics, and emergency resuscitative pharmaceuticals. By engaging your pharmacist you can also develop infusions and solutions to meet most special needs of your patient. For example, the pharmacist can make 3 or 7.5% NaCl solutions (or higher), 5% albumin, and solutions to perform peritoneal dialysis. Several formulations of enteral feeding solutions are available as are the abilities to provide peripheral parenteral and total parenteral nutrition when required. Basic supplies such as dressings, sterile gloves, and other disposables such as central lines, pressure transducers, tube thoracostomy trays, and ventilator circuits found in a modern day ICU are typically available. You should become familiar with your unit's list of medications, infusions, and supplies prior to deployment. Most units also include sequential compression devices, advanced airway equipment including fiberoptic bronchoscopy, and negative pressure wound therapy supplies.

What If I Have Scarce Resources and Too Many Critical Patients?

Unfortunately, you may be required to perform triage in the purest form for mass casualty incidents but also on occasion to maximize available resources. This process of sorting out those that may benefit the most from high dependency care when the ratio of resources to patients is low can be difficult. The potential requirement to allocate resources places emphasis on pre-response logistics and careful attention to contingencies for rapid patient evacuation.

Several simple factors should be included in pre-response planning. These include: (1) making triage decisions based on available resources; (2) modifying standards of care to provide support to greater numbers of patients; and (3) limiting critical care interventions to only those clearly associated with improved survival as well as those interventions that are simple, individualized, and do not consume extensive resources.

The austerity of far-forward ICU's and potential for limited resources emphasizes the role of evacuation or transfer to other healthcare facilities. Critically ill patients should always be transferred from far-forward ICU's at the earliest safe opportunity to free up resources. U.S. and NATO ally forces can be managed through conventional evacuation methods but may require the Air Force's Critical Air Transport Team (CCATT). The CCATT operations have been another great success story coming out of the current combat operations in Iraq and Afghanistan.

In previous conflicts the medical evacuation process had often been a weak link in the evacuation chain, particularly for high acuity patients. In the current operations, these teams have provided a fully functional "ICU in the Sky," capable of advanced ICU monitoring, therapy, and interventions (Fig. 29.4). Thus the critically injured patient can be maintained in a continuous ICU environment from the forward combat hospital to the level IV facility (Landstuhl). These teams are usually based out of aeromedical evacuation points but can be used to augment tactical aeromedical and ground evacuation when required. A CCATT can manage up to three mechanically ventilated and critically ill patients including those requiring en route resuscitation. Critical care providers and surgeons should create and practice contingency plans for the transfer of critically injured/ill host nation patients, prisoners, and other foreigners.

Surgeons should be familiar with the principles of triage and understand the legal and ethical dilemmas associated with changes in medical practices and rationing of life-saving interventions associated with providing care during mass casualty incidents and limited resource availability. Low yield but labor or supply intensive interventions should not be pursued during mass casualty situations, as they will exhaust not only your supplies and equipment, but also your personnel. Always remember that your personnel are your KEY asset and must be conserved and protected whenever possible.

Fig. 29.4 Full ICU-level care and interventions are now able to be delivered during air evacuation by the Air Force Critical Care Air Transport Teams (CCATT)

Random but Practical and Important Points for the ICU

1. Most "ICU nurses" in Army Level II/III facilities do not have critical care training. They are, however, typically enthusiastic, hard working, and willing to learn. Train them well and they will perform beyond your expectations.
2. Avoid acute kidney injury by limiting IV contrast, aminoglycosides, THAM, other nephrotoxins, and identifying and treating rhabdomyolysis early and aggressively. You will not typically have dialysis as a bailout option.
3. Avoid abdominal compartment syndrome by monitoring fluid resuscitation and performing serial examinations. Monitor peak/plateau airway pressures and urine output.
4. Avoid central line infections by removing central lines placed in the ED or OR without proper sterile precautions and remove all central lines as early as possible.
5. Avoid polyneuropathy by limiting muscle relaxants and corticosteroids.
6. Avoid ventilator-associated pneumonia (VAP) by performing frequent oral care, proper feeding tube placement, monitoring tube residuals, and keep the head of bed elevated ALWAYS.
7. Avoid using etomidate unless absolutely required to avoid adrenal suppression.
8. Consider adrenal insufficiency in patients requiring vasopressors despite adequate intravascular volume replacement.
9. Consider alcohol and illicit drug withdrawal (even in Muslims) in patients with tachycardia and fever.
10. Avoid resuscitation injury by limiting crystalloid infusion.
11. Consider early use of vasopressors (i.e. vasopressin) to treat significant vasoplegia seen after major trauma and resuscitation.
12. Learn advanced ultrasound techniques. Among the usual diagnostic capabilities portable ultrasound can also be used to diagnose intracranial hypertension, pneumothorax, deep venous thrombosis, skin abscess, cardiac dysfunction, and vascular problems.
13. Perform daily sedation breaks.
14. Decontaminate equipment between patient uses.
15. Avoid overuse of antibiotics and limit antibiotic use to less than 8 days for non-*pseudomonas* ventilator-associated pneumonia.
16. Only sample blood and obtain x-rays when clinically indicated.
17. Consider regional anesthesia techniques to manage pain.
18. If there is a chance that you may be managing pediatric patients ensure that your equipment list includes a Broselow Tape and pertinent supplies (e.g. endotracheal tubes and central lines unique to pediatric patients).

Final Thoughts

The combat ICU is a place where stark realities of war are often highlighted, but also where miracles of care and compassion occur daily. The current conflicts have greatly facilitated the consolidation and acceptance of the practice of ICU medicine as a separate and critical link in the chain of survival from the battlefield to the stateside hospital and discharge. Ensure that you develop all of the physical characteristics of a high-quality ICU that have been described here, but that you extend the concepts of critical care wherever they are needed; typically the ER and the OR. Your hard work and dedication may not be rewarded with medals of valor, but instead the far greater reward of a job well done and a soldier who makes it home to his or her family.

Chapter 30
Postoperative Resuscitation

Martin A. Schreiber and Richard A. Nahouraii

Deployment Experience:

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BLUF Box (Bottom Line Up Front)

1. Damage control surgery and resuscitation occur simultaneously. Failure to stop hemorrhage precludes successful resuscitation.
2. Patients lose blood in the field. The traumatically injured combatant in shock needs blood products, not crystalloid.
3. Beware of the CVP. It is usually calibrated and measured incorrectly, and even when done correctly shows little ability to predict preload and volume responsiveness.
4. A patient with a normal blood pressure and good urine output may still have compensated shock. Trending serum lactate in combination with base deficit is the best way to assess oxygen delivery and consumption and hence determine if resuscitation is succeeding.
5. In the post-damage control ICU patient who is failing resuscitation, ongoing bleeding and occult tissue ischemia must be strongly considered. Take the patient back to the operating room.
6. Over-resuscitation is as bad as or worse than under-resuscitation – stop when goals are met to avoid the "dry-land salt water drowning" syndrome.
7. Develop a general approach and philosophy to resuscitation goals and methods that everyone agrees on. Make it easy and make it as automatic as possible.

A good heart and kidneys can survive all but the most willfully incompetent fluid regimen.

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Introduction

You have just completed a major damage control operation with significant blood loss and ongoing resuscitation. As the patient rolls through the ICU doors, you are asked to write orders for the nurses to begin the postoperative care phase. You may or may not have an “intensivist” available to help you. Having a clear vision and plan for performing and monitoring the postoperative resuscitation is critical to avoid the twin evils of under resuscitation and over resuscitation. In combat surgery this is particularly critical as you often have to hand the patient off to the nurses or another physician and return to the ER or OR. Having a general approach or “philosophy” to resuscitation that the nurses, surgeons, and other physicians agree with and understand can make this process much smoother and less confusing.

Principles of Combat Resuscitation

The concepts of postoperative resuscitation and damage control surgery are inextricably linked in the combat environment. Presented with the critically injured patient, the surgeon in a combat environment must rely upon the guiding concepts of damage control surgery: stopping hemorrhage and controlling contamination. Definitive operations with anatomic reconstruction are delayed. Resuscitation and the restoration of normal physiology are the objectives, accomplished in the intensive care unit and aimed at either correcting or preventing the lethal triad of hypothermia, metabolic acidosis, and coagulopathy. Furthermore, resuscitation is a dynamic process, often occurring over hours or days, after injury. Combat resuscitation should be viewed as a continuum of care as outlined in Fig. 30.1.

The goals of therapy in the ICU after damage control surgery are well-defined: (1) correct metabolic acidosis; (2) restore normothermia; (3) reverse coagulopathy; and (4) ensure adequate oxygen delivery and consumption. The components of the lethal triad act synergistically. Hypothermia and acidosis exacerbate coagulopathy by impairing clotting factor function. Each of the clotting factors are proteases that have enzyme kinetics dependent on an optimal pH and temperature. All three components of

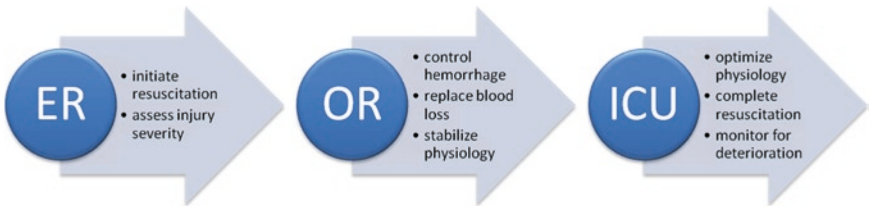

Fig. 30.1 The trauma resuscitation process can be seen as a continuum of care rather than fragmented episodes, beginning in the prehospital and emergency room (ER) and proceeding through the operating room (OR) and intensive care unit (ICU) phases

the triad must therefore be addressed simultaneously. The cornerstone of resuscitation in hemorrhagic shock (and the focus of this chapter) is ensuring adequate oxygen delivery by restoring an adequate circulating volume. Resuscitation is dynamic, and the goal is not merely to replenish circulating volume and restore oxygenation but to do so in a guided fashion, avoiding the complications of over-resuscitation. In an austere environment, the usual panoply of ICU hemodynamic monitoring devices, laboratory support, and even certain blood products may not be available. Fortunately, most advanced monitoring devices and laboratory equipment of the modern ICU are not necessary in the deployed environment.

What Fluids Should I Use? When Do I Give Blood Products?

ATLS guidelines recommend the initial administration of 1–2 L of lacated Ringer's solution (LR) or normal saline (NS) followed by an immediate assessment of the response of the arterial blood pressure as the preferred initial resuscitation maneuver in hemodynamically unstable patients. The goal is to differentiate patients into one of three categories: responder, transient responder, and non-responder. If after the initial 2 L of crystalloid, the patient fails to respond, or transiently responds but then again develops hypotension, blood is transfused. Accordingly, several points regarding this approach and its application to the combat environment deserve mention.

The first point that you should understand is that ATLS is geared toward blunt trauma and the target audience is primarily those inexperienced in trauma, or "amateurs." You are not an amateur, and should not approach trauma with a generic and basic algorithm. Do not spend 30 min in the Emergency Department with a critically injured patient trying to infuse liters of crystalloid to determine if the patient is a "responder," or trying to get the blood pressure up to some arbitrary level. In combat trauma this will get you way behind the power curve at the least, or a dead patient. Combat trauma patients that are stable and mentating do not need any initial large fluid volumes, particularly cold crystalloid solutions. The vast majority of patient with compensated or uncompensated shock on presentation need resuscitation in tandem with operative intervention, and this resuscitation should start and end with blood products.

If you resuscitate postoperatively with standard crystalloid solutions (normal saline), you may see several adverse affects due to the large sodium and chloride loads. The most immediate clinical consequence of this iatrogenic hyperchloremic metabolic acidosis is to confound the interpretation of blood gas pH and base deficit values obtained during the resuscitation. In the worst case, a persistently decreased pH or base deficit could be misinterpreted as ongoing hypoperfusion and treated with further volume expansion thereby exacerbating the problem. This affect will be worse with normal saline compared to a more balanced solution like lactated Ringer's (LR).

There are currently no data to support the use of colloids over crystalloid for the resuscitation of hemorrhagic shock. Colloids are generally more expensive than crystalloid and they may be associated with negative effects. Starch solutions such as Hespan® may induce coagulopathy at high (>20 mL/kg) doses. Albumin, which is frequently used for post-trauma resuscitation, is a human product with attendant potential infectious risks. Hextend® is composed of 6% hetastarch in a balanced electrolyte solution. Its infusion has been shown, in a prospective randomized study, to result in reduced blood loss and coagulopathy in patients undergoing large elective surgical procedures compared to Hespan® (which is hetastarch in normal saline). While Hextend® is currently used in the field for Tactical Combat Casualty Care largely due to its ability to restore intravascular volume with smaller quantities than crystalloid, its role in the trauma bay or ICU is limited.

Another common misconception in the ICU is the practice of ordering "maintenance fluids." This is a ward medicine concept designed for a euvolemic patient to replace normal daily losses. Your ICU patient will be either volume depleted or volume overloaded, particularly immediately after a major surgical procedure. Do not write for maintenance fluids simply out of habit, as this is ineffective for volume expansion and deleterious in the overloaded patient. Give bolus therapy as needed, or hold fluids and allow the overloaded patient to equilibrate.

Before beginning your postoperative resuscitation, the first step is determining whether it is even required. Review the operative record for fluids/blood products given and blood loss, as well as the extent of injuries and procedures performed. Discussion with the surgeon directly will be the best way to get a sense of whether ongoing fluid losses or bleeding are expected. Obtain immediate labwork to establish a baseline for the hematocrit, platelet count, coagulation panel, and lactate or base deficit. Examine drains, tubes, and wounds for ongoing blood loss. In combat trauma, your postoperative resuscitation fluid of choice for hypotension and/or coagulopathy is blood products in a 1:1:1 ratio. A simple rule of thumb is to administer red blood cells until you have a stable hematocrit of at least 25 and plasma until the INR is less than 1.8. In addition to correcting coagulopathy, plasma is an excellent early resuscitation fluid with colloid volume expansion properties.

How Do I Tell If I Am Winning or Losing the Battle? What Is the Best Endpoint?

After damage control surgery and damage control resuscitation have controlled hemorrhage and contamination, the goal of resuscitation is to restore adequate tissue oxygenation by normalizing intravascular volume. The questions of when adequate oxygenation and intravascular volume have been achieved are not straight forward. When traditional parameters of resuscitation such as systolic and mean arterial blood pressure, heart rate, and urine output have normalized, up to 85% of severely injured patients may still have inadequate oxygen delivery, a state known as compensated shock. Attempts to guide resuscitation toward supranormal values of oxygen delivery, oxygen consumption, and cardiac output have met with limited success. It appears that patients who achieve supranormal levels of oxygen delivery have a better survival than those who cannot achieve these levels, but no evidence exists that attempting to attain such levels directly improves survival. Oxygen delivery is a function of cardiac output, hemoglobin, and oxygen saturation. Therefore, options for improving oxygen delivery include increasing cardiac output, transfusing blood or increasing oxygen saturation.

Since volume resuscitation is the primary means to improving cardiac output, various hemodynamic monitoring endpoints have been advanced as guides to resuscitation. Central venous pressure (CVP), pulmonary artery occlusion pressure (Ppao, often incorrectly referred to as pulmonary capillary wedge pressure), and more advanced volumetric measures of preload such as right ventricular end diastolic volume index (RVEDVI) and global end diastolic volume index (GEDVI) have been studied. With the exception of CVP, these require specialized equipment and/or training not present in most forward deployed facilities. Dependence on the CVP should be limited. Even when it is measured and interpreted correctly (from waveforms, not from the mean pressure displayed on the monitor) in a ventilated patient with no active expiration and reasonable levels of PEEP, the CVP does not appear to reliably predict volume status or volume responsiveness. The trending of CVP is a more useful tool than individual measurements, as there is a wide variation in baseline CVP between patients. Use CVP as one additional data point in your algorithm, and not as a primary factor directing management decisions. Chapter 6 describes a useful technique for bedside ultrasound assessment of the size and collapsibility of the vena cava which can provide a real-time assessment of CVP and volume status.

The best and most feasible markers of resuscitation adequacy should be obtainable without specialized equipment and they should be easy to interpret. Metabolic parameters show the most usefulness in assessing resuscitation from shock. The arterial base deficit, serum lactate, and central venous oxygen saturation (CvO2) are all readily available measures from standard blood-gas analyzers. Although they assess oxygen delivery and tissue hypoxia globally and not regionally, they provide the most consistent measures of shock severity and resuscitation response. Serum pH is a useful measure, but is too easily influenced by respiratory factors and renal function to provide a reliable pure marker of tissue perfusion.

The arterial base deficit is an easily obtained and widely used measure in trauma. Investigators have demonstrated that the initial base deficit on presentation correlates with survival and trends in the base deficit predict the success or failure of resuscitation. A base deficit of 5 mmol/L or greater is a marker of severe injury and should prompt further assessment and intervention. It is important to understand that you are using the base deficit as a surrogate for lactate, but several factors can disrupt the correlation between these two measures. These include hyperchloremic acidosis from saline overload, alcohol intoxication, and acidosis secondary to renal failure. In these situations, an elevated base deficit may have little or no prognostic significance.

Due to these limitations of the base deficit, lactate has become favored as the best biochemical marker for its specificity and predictive value. Although initial lactate values have been shown to correlate with outcome, lactate trends over time correlate better with survival. If you have the ability to check lactate levels, obtain one immediately postoperatively and then 4–6 h during the early resuscitation. Your goal is normalization of the lactate level (<3 mmol/L) within 24 h, which predicts a greater than 90% survival. Failure to correct the lactate level within 48 h is associated with a

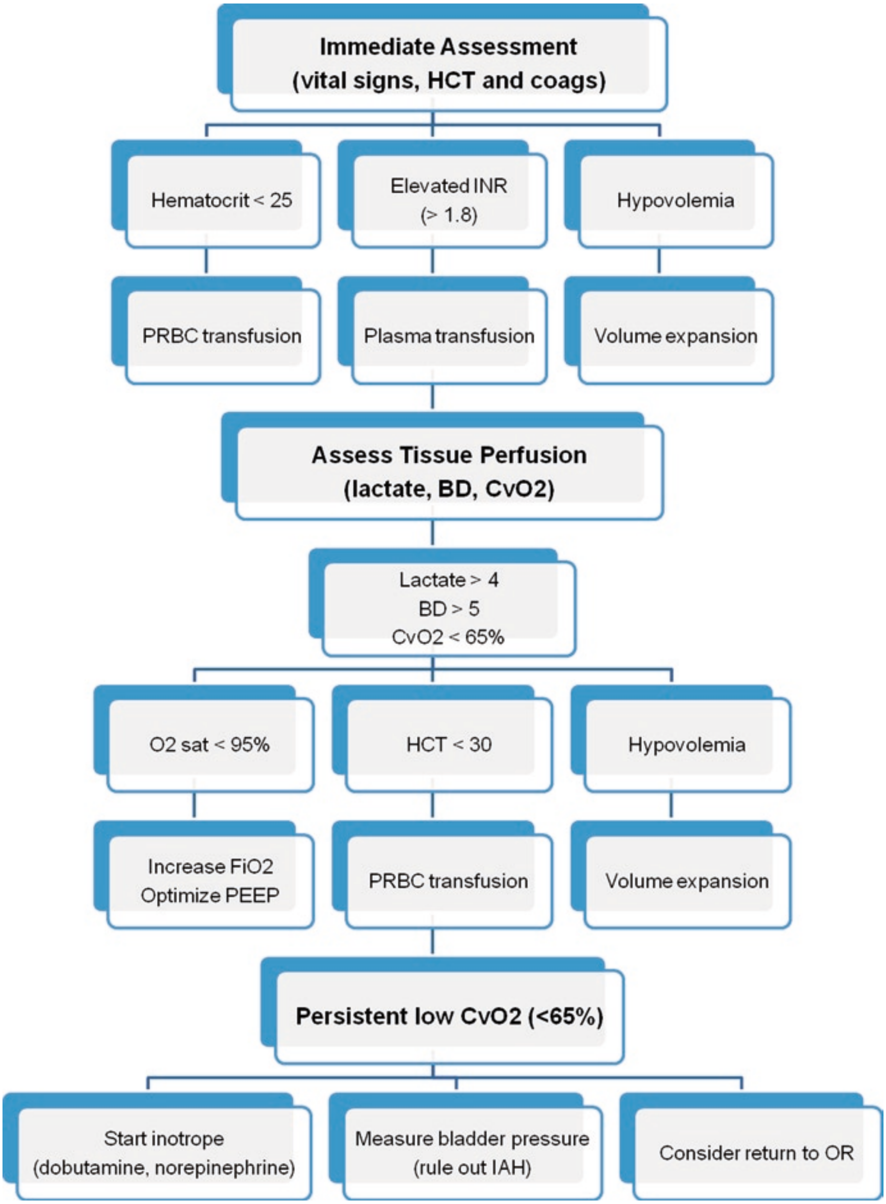

Fig. 30.2 Example of a postoperative resuscitation algorithm based on physical examination, vital signs, and routine laboratory parameters. *INR* international normalized ratio, *FiO2* fraction of inspired oxygen, *IAH* intra-abdominal hypertension (pressure >20 mmHg)

mortality of 80–100%. The lactate clearance time will also predict postoperative complications such as infection: Lactate normalization within 12 h is associated with a 10–15% infection rate while normalization beyond 24 h is associated with a markedly increased (>60%) incidence of infection.

Measurement of the central venous oxygen saturation (CvO2) is being increasingly utilized in a variety of ICU populations, including trauma and major surgery. Obtain a venous blood gas from the central venous catheter. The CvO2 is the oxygen saturation value (not the pO2, which is a common mistake) and normal values are in the 65–80% range. This measure reflects the adequacy of tissue oxygen delivery and the amount extracted, with levels below 65% indicating inadequate delivery. If the CvO2 is less than 65%, then a stepwise approach is initiated to maximize the key factors in oxygen delivery. First, optimize the intravascular volume status and ensure the hematocrit is at least 25. If the CvO2 remains low then transfuse to get the hematocrit to ≥30. Ensure that the oxygen saturation is as close to 100% as possible. If the CvO2 remains low then the next culprit is the cardiac output. Although cardiogenic shock is less common in the average young trauma patient, it can be seen with major chest trauma, arrhythmias, or sepsis. A cardiac inotrope such as dobutamine or norepinephrine should be started and then assess for any improvement in CvO2. This is often a trial and error process, but it should be done in an orderly and rapid manner. Figure 30.2 outlines a basic algorithm to approach the early postoperative resuscitation.

One of the least discussed aspects of postoperative resuscitation is the role of pressor agents. Standard surgical teaching is that there is no role for early pressor use, and resuscitation should focus on volume administration, followed by more volume. There is growing interest in the efficacy of earlier introduction of pressor agents for hypotension during resuscitation. It is now appreciated that the early response to major trauma is not purely due to volume depletion, but also represents a variety of factors including vascular permeability, cardiac dysfunction, and resistance to naturally produced catecholamines and vasopressin. It would therefore make sense that pressors could be of benefit in maintaining perfusion and in avoiding overzealous crystalloid administration. There is also accumulating animal data that early pressor use in hemorrhagic shock markedly improves survival compared to volume and blood resuscitation alone. Pressor agents may also contribute to hemorrhage control by vasoconstriction and redistribution of blood flow. In the patient with refractory hypotension despite an adequate volume load (particularly those with associated brain injury), we recommend initiation of a balanced pressor agent (norepinephrine, dopamine) while resuscitation is continued and other causes (i.e. recurrent hemorrhage) are addressed.

Who Does Not Need Resuscitation?

One of the hallmarks of expertise in postoperative resuscitation is the ability to identify patients who do not require any resuscitation, or even require immediate volume removal. The easy (and often expected) practice is to continue large volume fluid administration until every last number has normalized or is supranormal. Withholding fluids in the early postoperative period is often criticized or looked upon as heresy, but this is pure dogma. If the surgeon and anesthesia provider did their job well and there is no ongoing contamination or bleeding, then the patient will often arrive to the ICU fully resuscitated or even overloaded. As described above, you must rapidly establish a baseline assessment of the patient's status based on the injuries and operations performed, vital signs, urine output, and laboratory parameters. If the measures of tissue perfusion and adequate oxygen delivery are normal (lactate < 2, base deficit < 5, central venous O2 sat > 70%), then there is little that you can improve by adding additional fluid. You will best serve the patient by minimizing unnecessary fluids and closely follow these parameters every 2–4 h to adjust your plan. You will be rewarded with decreased incidences of organ failure and abdominal compartment syndrome, and faster times to extubation.

When Do I Need to Go Back to the OR?

As resuscitation proceeds, following conventional parameters such as the blood pressure and urine output in conjunction with lactate and base deficit will be important. The hematocrit will also help guide resuscitation but less so than the other variables as hematocrit is affected by both loss of red cell mass and infusion of fluids. As urine is produced and the lactate and base deficit normalize in the face of continued hemodynamic stability, the resuscitation may be assumed to be progressing well and fluid administration should be minimized. Increasing lactate, increasing base deficit, decreasing CvO2, or hemodynamic instability should induce a rapid and aggressive search for ongoing hemorrhage and devitalized tissue or ischemia. Wounds should be examined for evidence of devitalized tissue, and the extremities should be assessed for vascular integrity. Ongoing cavitary hemorrhage or hemorrhage into extremity compartments may be difficult to assess. Chest tube output many not adequately reflect hemorrhage due to clotting so function of the chest tube should be assessed and a chest x-ray obtained to evaluate for retained hemothorax. Suspicion of uncontrolled intra-abdominal hemorrhage is an indication for exploration. Evidence of ongoing bleeding that persists despite adequate efforts to treat coagulopathy mandate an immediate return to the OR to control the source. Failure to do so will ultimately lead to catastrophe, and no amount of blood, plasma, or recombinant factor VIIa will salvage a patient who languishes in the ICU when they belong in the operating room.

Final Thoughts

You should think of the resuscitation as a continuous line that begins in the prehospital setting and continues through the ER, OR, and into the ICU. Therefore, understanding what has been already been done and where your patient is now will guide your postoperative resuscitation plan. Always be cognizant of the morbidity of excess administration of cold, coagulopathic, and acidotic solutions – i.e. standard crystalloids. This all too common occurrence of "dry-land salt water drowning" is now easily avoided with modern resuscitation principles. Be smart, be aggressive, and be focused on the important variables to achieve an effective combat resuscitation.

Chapter 31
Monitoring

Alec Beekley and Jay Johannigman

Deployment Experience:

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BLUF Box (Bottom Line Up Front)

1. No monitor can or should replace your eyes, ears, hands, or brain.
2. Young casualties demonstrate robust physiologic defense mechanisms and will defend blood pressure and pulse to the point of complete cardiovascular collapse.
3. "Compensated" shock may often be more accurately termed "unrecognized" shock.
4. The standard monitors available – pulse oximetry, electrocardiography, arterial lines, and central venous pressure – provide valuable but limited data.
5. Evaluation of shock and resuscitation should focus on parameters that reflect the adequacy of cellular oxygen delivery.
6. Pulse, blood pressure, and urinary output are notoriously unreliable indicators of adequacy of resuscitation – particularly in the young casualty.
7. There is not a single "best" endpoint of resuscitation.

(continued)

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BLUF Box (Bottom Line Up Front) (continued)

8. Base deficit, lactate, and venous oxygen saturation are reliable indicators of resuscitation.
9. Correction of coagulopathy is a valuable indicator that your patient is doing well.
10. Several novel technologies (e.g. NIRS StO2, closed-loop resuscitation and oxygenation) show promise and have been introduced into the combat setting; they should not replace your physical exam skills and judgment.

An increasing worship of instrument for its own sake sometimes leads to enslavement by it.

David Seegal

Introduction

During a discussion I was having about near-infrared spectroscopy (NIRS) derived tissue oximetry, an expert surgeon who has written a lot about NIRS, asked, "If we could have the perfect patient monitor, what would it look like? It would be non-invasive. It would be continuous. It would be reliable. It would be inexpensive, so you could use it repeatedly on anyone and everyone. It would tell us information that we couldn't figure out on our own. And it would not only tell us that something was wrong, it would tell us WHAT was wrong so we'd know what to do about it."

All of the monitors we currently have – even the new, high-tech ones – fall short of this ideal. The monitors you will have in theater will provide you with raw data, but it will still be up to you to put various pieces of data together with the appearance of the patient to determine what is wrong with the patient and what needs to be done. There is no special lab, test, monitor, or device that can tell you what is wrong with a patient and what to do. No monitor can replace your eyes, hands, brain, and judgment. With that in mind, the follow-on lesson is that the establishment of monitors, particularly invasive ones, should never take priority over the interventions necessary to save a patient. The words, "We're just going to get another central line and a-line in him, and then we'll go to the OR," should not come out of your mouth. Central lines or a-lines are almost never the intervention that saves a bleeding trauma patient's life.

Although heart rate and blood pressure may be inadequate to gauge resuscitation, they are frequently sufficient as a triage tool to separate those that need immediate operation from those that do not. The character of the radial pulse and a simple GCS motor score can fairly reliably separate the "sick" from the "not sick." This is particularly true if keen attention is paid to other non-measurable clinical signs (skin color, mental status, obvious physical signs of injury, etc.).

Fig. 31.1 Ubiquitous portable monitoring unit used in deployed Army surgical units. Continuous electrocardiographic tracings, pulse oximetry, temperature, and respiratory rate are standardly displayed. This particular monitor also reveals end-tidal CO2 monitoring in an intubated patient

Rapid point-of-care testing (INR, base deficit, lactate) can provide confirmatory data. Invasive continuous monitoring is almost never required for this initial decision process. Typically, a simple pulse oximeter, electrocardiographic, and respiratory rate monitor are rapidly established and provide adequate continuous data for patients needing transfer from the trauma bay to the OR or CT scan (Fig. 31.1). All surgical units will have this basic monitoring capability. The other standard monitors available at the Forward Surgical Team and Combat Support Hospital include arterial lines and central venous pressure. More advanced continuous monitors, such as continuous central venous saturation, intra-cranial pressure, near-infrared spectroscopy-derived tissue oxygenation, and non-invasive cardiac output monitors will only be available at selected facilities.

Pulse Oximetry

The ubiquitous pulse oximeter device consists of a light source and a detector that fits around the finger, toe, or ear lobe. It passes visible (red) and infra-red spectrum light through the tissues and, based on values programmed into the device, can detect the different amounts of red and infra-red light that are absorbed or transmitted through oxygenated and deoxygenated hemoglobin in the blood vessels. The percentage of oxygenated blood can be calculated automatically by the device. The pulse rate is also displayed.

Several problems or conditions can cause the pulse oximeter to provide faulty readings. Patients in profound shock, elderly patients (particularly those with vascular disease), and profoundly cold extremities may have poor perfusion of their digits and the oxygen saturation may be falsely decreased and/or pulse rate may not be detected. Patients with carbon monoxide and cyanide poisoning may have falsely high O2 saturations as detected by pulse oximetry; conversely, patients with methemoglobinemia will characteristically have an oxygenation value in the mid-80s. It is critically important that you look at not only the number being displayed on the monitor, but also the waveform. You will frequently see false values of 95–100% saturation displayed when there is no discernible waveform.

For the combat environment, the relevant things to remember are that the pulse oximeter may be unreliable in casualties in profound shock – and in these cases, the value of the pulse oximetry should not be decisive anyway. Casualties may also have profound hypothermia, even in the hot desert; others may have cold weather exposure as well. Finally, casualties are sometimes trapped in burning vehicles or buildings and may have a carbon monoxide exposure. All of these scenarios may affect the accuracy and reliability of the pulse oximetry reading.

Electrocardiography/Telemetry

Electrocardiographic monitoring is also standard for combat casualties and is available in most medical units, all surgical units, and aeromedical units. There are essentially no downsides to continuous monitoring of electrocardiographic tracings, and most trauma bay personnel get used to rapidly applying these to casualties. Unfortunately, the data obtained from these tracings are somewhat limited, at least from the standpoint of rapid decision-making in trauma. The cardiac telemetry monitors do not provide much additional information aside from heart rate, particularly in young, otherwise healthy casualties. There are instances where older foreign national patients, contractors, and even soldiers may suffer cardiac ischemia, and these monitors can be useful in that setting. The monitors are also useful for easy, continuous monitoring in the intensive care unit and are standard in ICUs throughout the world. One key point: if your patient suddenly become asystolic, check that the leads have not fallen off or the cable has become disconnected before you crack the chest open.

Central Venous Pressure

Continuous monitoring of central venous pressure (CVP) is available in most surgical units, but the utility to reliably determine volume status and monitor resuscitation is limited. Probably the most important thing to remember in the trauma bay is that the placement of a central line should be to establish large-bore access to give volume, medications, and blood products, NOT to be used as a monitor. If adequate large-bore IV access has already been established, central line placement is not a valid reason to delay taking the patient to the OR. Central lines can be placed by anesthesia personnel while the surgeons operate. Once the central line has been established *in the appropriate setting*, the best monitoring data it will provide is through intermittent assessments of the central venous oxygen saturation.

One of the biggest fallacies in critical care that continues to be taught and practiced is that central venous pressure is an accurate reflection of ventricular preload. While this looks reasonable on diagrams, the reality is that this is an "estimate of an assumption about a surrogate." The lack of correlation between CVP and volume status has been proven in multiple studies, even among healthy volunteers where the relationship between end-diastolic volume and CVP should be the most reliable. While it may have some use at the extremes of measurement (complete volume collapse or massive volume overload), CVP IS NOT AN ACCURATE OR RELIABLE REFLECTION OF INTRAVASCULAR VOLUME! Changes in CVP can just as easily reflect changes in patient position, monitor position, respiratory pressures, and most importantly ventricular compliance. It is also highly user and interpreter dependent; we have found that drastic CVP changes more often reflect a nursing change of shift than they do fluid shifts. You will be much better off using some of the alternative measures for assessing volume status outlined in this chapter and in Chap. 6 (Ultrasound).

Venous Oxygen Saturation

The term mixed venous oxygen saturation (SvO2) refers to the hemoglobin saturation of blood in the proximal pulmonary artery. Central venous oxygen saturation (CVO2) refers to the hemoglobin saturation in the superior vena cava (or other central vein). When oxygen *supply* provided by the cardiopulmonary system is insufficient to meet the bodily/cellular oxygen *demand* there is a resultant increase in oxygen extraction at the tissue level. This state of increased extraction is manifested by a decrease in the venous oxygen content. Monitoring of venous oxygen content therefore serves as a third parameter of adequacy of resuscitation as well as a means of monitoring the cardiac output and the progressive status of ongoing resuscitation.

Traditionally the monitoring of venous oxygen saturation has required the placement of a pulmonary artery catheter in order to obtain sample(s) from the pulmonary artery (SvO2). The logic of this approach recognizes the variability and sampling error that may be introduced by the contribution of cardiac return via the coronary sinus. The contribution of the effluent of the coronary sinus is significant and may (or may not) be accounted for by a central venous line. This anatomic and physiologic consideration is the basis for the traditional use of SvO2 as the correct measurement of venous oxygen saturation (requiring full admixture of venous blood in the right ventricle) for truly representative sampling of venous oxygen content.

A number of recent studies have attempted to identify a correlation between mixed venous saturation (pulmonary artery catheter) and central venous saturation (CVP line). These studies have reached alternative conclusions regarding the absolute correlation between individual observations of SvO2 and CVO2. However, what can be concluded from these studies is that although individual observations may vary, the *trend* in SvO2 closely approximates the trend in CVO2 and may be used as an accurate surrogate (Fig. 31.2). The author recommends the use of CVO2 (via central venous sampling) as a means of tracking the direction and trend of an ongoing resuscitation. Most combat casualties with significant injuries will have a central line placed in anticipation of needs for resuscitation and transport by the CCATT team. The availability of CVP lines in combat casualties affords the opportunity for frequent and simple sampling of the trend in CVO2 as a means of monitoring the progress of an ongoing resuscitation. Limited studies in the setting of hypovolemic shock (animals and humans) have demonstrated the utility of monitoring venous saturation as a marker of the severity of shock as well as its subsequent resolution during resuscitation. To date, there has not been a prospective study examining the efficacy of venous saturation as an endpoint of resuscitation in trauma patients. A study completed in medical patients did demonstrate that the use of CVO2 is a valid endpoint of resuscitation capable of altering mortality, and superior to standard goals. In the setting of trauma patients, positive trends in the resolution of venous desaturation have been demonstrated to be associated with improved survival. It is the authors' belief that monitoring of venous saturation (SvO2 or CVO2) is much more reliable and meaningful than the oft-quoted standards of heart rate, blood pressure, and urinary output. This is especially true in the young and otherwise healthy combat casualty. In addition to helping guide your resuscitation, this data can also prevent the other cardinal sin: over-resuscitation. If you have an isolated abnormality (tachycardia, low blood pressure, borderline urine output) but your CVO2 and other markers (hematocrit, lactate) are reassuring, then you do not have to chase the abnormality with more volume resuscitation.

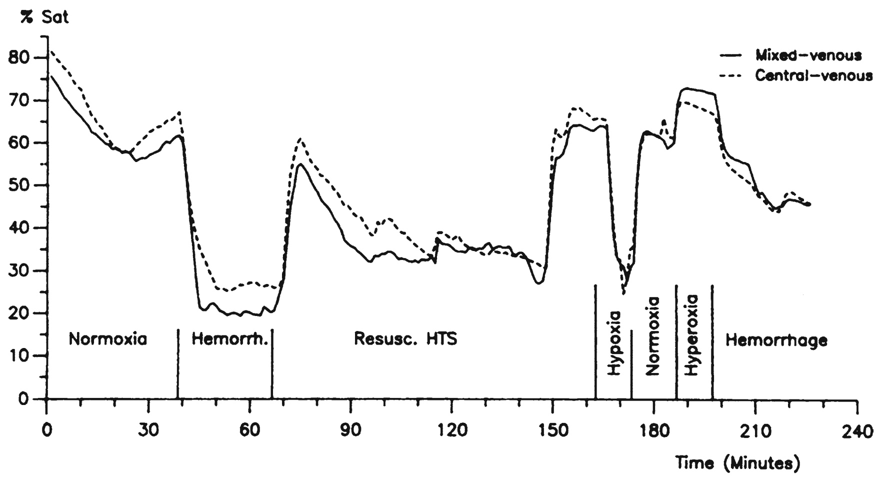

Fig. 31.2 Strong correlation between mixed and central venous oxygen saturation across a variety of physiologic extremes (reprinted with permission from Reinhart et al., Chest 1989;95:1216–1221)

Pulmonary Artery Catheters

Although some combat support hospitals may actually stock a few of these devices, there are very limited applications for their use in the combat setting. The most common use of pulmonary artery catheters in forward surgery has been as an improvised embolectomy catheter or occlusion catheter for vascular repairs in the operating room. The patients are predominately young, healthy men and women who happened to suffer severe penetrating trauma. There is rarely any confusion about their cardiac function, and volume status may be assessed by other means. If you happen to be in a unit that stocks these devices, keep in mind that in addition to the device, their use requires specialized monitors and skilled intensive care nurses. Finally, there is no quality data to support pulmonary artery catheter use in trauma patients – if anything, it may be harmful because of misleading data. If you do have these available and do use them, then you should always follow these basic principles: (1) Level the device and read your numbers from the waveform, not from the averaged numbers on the monitor; (2) Repeat your measurements several times to ensure consistency; (3) Do not use it as a "wedgometer"; among all of the data provided by this device, the filling pressures are less accurate and useful than the volume indexes (cardiac index, stroke volume index) and getting a true mixed venous oxygen saturation (SvO2).

Arterial Lines

Arterial lines have substantial utility in the treatment of combat casualties – *as long as their placement does not delay transfer to the OR.* The preferred sites for placement are in the radial arteries, but if you are struggling or fail at the wrist, don't hesitate to place a femoral arterial line. Brachial arterial lines and other end arterial lines have been associated with potential ischemic complications – they should be avoided if other alternatives are available, and removed as soon as possible if they are used. Establishment of an arterial line allows second-to-second monitoring of blood pressure and withdrawal of blood specimens for standard labs, arterial blood gas, and lactate levels. Adequacy of resuscitation cannot be directly gained from the arterial line tracing, but the trend may at least be able to tell you if you are headed in the right direction.

With new software and waveform analysis algorithms, a wealth of data about volume status and cardiac function can be obtained from an arterial line. This technology is being increasingly used in civilian ICU settings, and is a promising innovation which can be easily extended to the combat theater. As an example, the Vigileo Monitor (Edwards Lifesciences LLC, Irvine, California) uses input from a high-fidelity arterial line to estimate the cardiac stroke volume (and thus cardiac output), which can be combined with standard blood gas data to estimate oxygen delivery and consumption. A second order analysis of the same data can examine the variations in the cardiac stroke volumes during the respiratory cycle, and provide an estimate of the intravascular volume status (Fig. 31.3). The continuous nature of this data makes it ideal for both point assessments

Fig. 31.3 The Vigileo Monitor (Edwards Lifesciences LLC, Irvine, California) extracts data from a radial artery catheter (arrow) to provide reliable estimates of stroke volume (SV), cardiac output (CO) and stroke volume variability (SVV)

and for assessing the response to resuscitation and other interventions. Expect to see more of this type of technology being used in the far forward ICU setting.

Assessing Volume Status: The Holy Grail

The inventor of the device that can provide a quick, easy, and ACCURATE bedside estimate of intravascular volume will be a wealthy person indeed. For most of your patients in the early phases of resuscitation there will not be much of a mystery – they need volume. The harder part is figuring out when enough is enough in order to avoid over-resuscitation injury, and sorting out what is going on when the patient is heading in the wrong direction. As previously mentioned, I would not list CVP (or even wedge pressure) within my top ten options for assessing volume status. Rather than measure the pressure in the vena cava, you can put an ultrasound probe on the abdomen and directly measure the size of the inferior vena cava, as well as assess the amount of collapse with respiration (see Chap. 6). This well known physiologic phenomenon of respiratory variability in hemodynamics can be used to your advantage at the bedside to evaluate volume status even without an ultrasound. In addition to estimating the stroke volume and cardiac output as described above, the Vigileo monitor can also assess the respiratory variability in stroke volume to provide an estimate of whether the patient will be volume responsive or not (Fig. 31.4). This same principle can be applied to most hemodynamic measures; watch your CVP tracing or your arterial line tracing for how much they change between peak inspiration and peak expiration. Larger fluctuations are indicative of volume depletion and that there will be a positive response to volume infusion. This is most useful in a patient who is intubated and on fully controlled positive pressure ventilation, where the pressures should be highest during inspiration and lowest during expiration. REMEMBER THAT THIS PATTERN IS REVERSED (AND LESS RELIABLE) DURING SPONTANEOUS BREATHING.

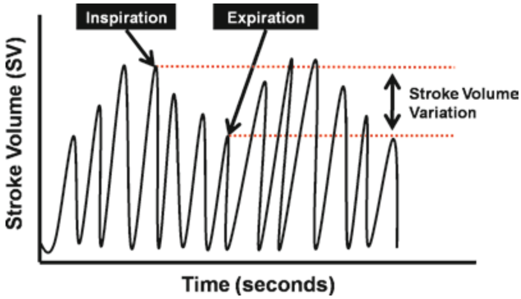

Fig. 31.4 Stroke volume variation with the respiratory cycle during mechanical ventilation. A variation of greater than 10–15% accurately predicts that the patient will be responsive to volume infusion

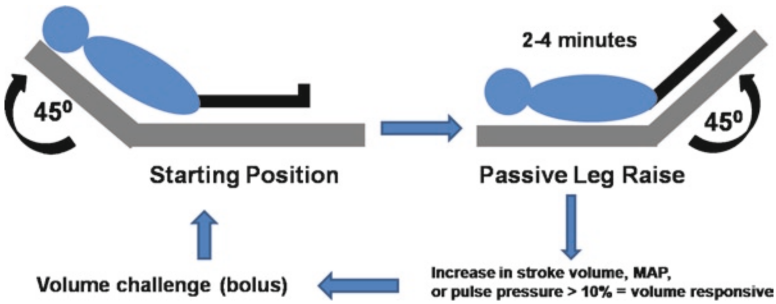

Fig. 31.5 The Passive Leg Raise (PLR) test for volume responsiveness. If the selected hemodynamic parameter improves by greater than 10% with PLR, then a volume challenge is administered. The test can be repeated to assess response

A similar technique that is gaining wider acceptance is the Passive Leg Raise maneuver. This is done by moving the patient from the standard ICU bed-rest position (with 45° head elevation) to supine with the legs elevated to 45° (Fig. 31.5). In "volume responsive" patients this should result in significant improvement in central hemodynamics, with minimal change in euvolemic or volume overloaded patients. The bad news: traditionally this required a specialized probe to measure aortic flow, or transthoracic echocardiography. The good news: this technique has now been validated using the simple bedside measures of either mean arterial pressure (MAP) or pulse pressure (difference between systolic and diastolic pressure). As shown in Fig. 31.5, if your measure improves by greater than 10% (volume responsive) then you can proceed with a fluid bolus and then reassess. If the response is less than 10%, you can assume that the intravascular volume status is fine and look elsewhere.

Intracranial Pressure Monitors (ICP)

Neurosurgical assets are usually centralized at one or two fixed facilities in a combat theater, and patients requiring evaluation and intervention are expeditiously evacuated to these locations. If you are located at one of these centers, then you should become familiar with placing and interpreting ICP monitors as they will be commonplace. However, even surgeons who are not located at a neurosurgical center should understand these monitors and how to use the basic data that they provide. There have been many cases of emergent craniotomies being performed by general surgeons in far forward locations, and you may have severely head injured patients that you cannot transfer due to weather, stability, or the medical rules of engagement. Chapter 24 provides an excellent description of the options and techniques for placing these devices. The general criteria for who should receive an ICP monitor are those with a traumatic head injury and a GCS of less than 8 (off sedation) or select patients with traumatic mass lesions. Additional indications include patients with a known or highly suspected brain injury and an inability to perform a head CT or a neurologic exam. This is typically the patient with multiple injuries who is rushed to the OR without a head CT, or who had a head CT showing a clear injury and will be under general anesthesia for a prolonged period of time (unable to examine).

If you have an ICP monitor, don't just read a number off of the monitor and use that in isolation. You must consider several factors, including the current absolute ICP level, the trend in ICP, and the ICP in relation to the systemic pressure. You should get concerned when ICP reaches 15, and any ICP above 20 or any rapidly increasing ICP should prompt immediate evaluation and intervention. Lower thresholds of concern should be used for hypotensive patients. In addition to the ICP value, important information can be gained from examining the ICP waveform. Figure 31.6 shows a normal ICP waveform and several abnormal examples. Progressive elevation of the

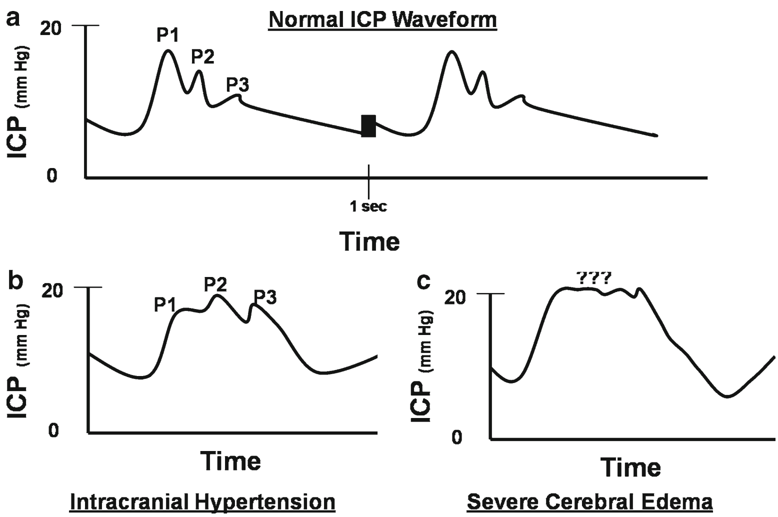

Fig. 31.6 (**a**) A normal ICP waveform has 3 peaks of decreasing amplitude, P1 (pulse wave), P2 (tidal wave), and P3 (dicrotic wave); (**b**) Increased amplitude of the tidal wave (P2) is seen with rising ICP and loss of cranial compliance; (**c**) Diffuse cerebral edema indicated by loss of the characteristic tri-phasic ICP waveform

P2 peak (tidal wave) in relation to the P1 peak indicates decreasing cranial compliance and may predict refractory intracranial hypertension (Fig. 31.6b). Diffuse cerebral edema and loss of compliance is typically reflected by a rounding or “monotony” of the waveform, with loss of the three distinguishable peaks (Fig. 31.6c). This is an ominous sign which typically indicates a poor prognosis in the absence of an identified and reversible cause (i.e. epidural hematoma).

Monitoring for Shock and Adequacy of Resuscitation

Shock is defined as inadequate oxygen delivery at the cellular level. In order to resuscitate a patient and eliminate shock it is appropriate to evaluate parameters that relate to the adequacy of oxygen delivery as endpoints of resuscitation. There is no single endpoint that has proven to be unequivocally predictive of shock, but all prove to be more reliable than the simple measures of heart rate, blood pressure, and urinary output. It is the responsibility of the clinician to understand the strengths and weaknesses of the various parameters utilized to assess adequacy of cellular oxygen delivery. Chapter 30 provides an in-depth discussion of specific “endpoints” of resuscitation. The reader should not expect to emerge with a simple formula, device, or parameter to guide resuscitation but rather should derive a balanced foundation of how assessment of adequacy of cellular oxygen delivery is a complex yet potent patient care tool. The EARLY recognition and correction of shock will require collection of multiple traditional parameters (base deficit, lactate, venous oxygen concentration, and INR) combined with solid clinical judgment. The remainder of this chapter will introduce several novel monitoring technologies for assessing shock and guiding resuscitation that you may encounter now or in the near future in the deployed setting. This includes near-infrared derived tissue oximetry, heart rate and R-R variability, and closed loop ventilation and resuscitation. These parameters are evaluated in the context of a progressive resuscitative paradigm that monitors the patient’s progress and physiologic response to therapy.

Correction of Coagulopathy

Traditional discussions of endpoints of resuscitation fail to include correction of coagulopathy as a targeted endpoint. The significant negative contribution of coagulopathy to the “lethal triad” (hypotension, hypothermia, and coagulopathy) has been demonstrated in numerous publications from the theater. Early correction of coagulopathy is an important component of Damage Control Resuscitation. The recent introduction of portable blood analyzers capable of measuring INR has made it possible to frequently test for the correction of coagulopathy as a measure of the adequacy of resuscitation. There is currently no literature to support the use of INR as an endpoint of resuscitation. This being acknowledged, it is the author’s experience that correction of INR to levels of less than 1.5 are a practical and pragmatic guide to the restoration of adequate splanchnic flow and global oxygen delivery. The corollary to this is that a rising INR despite aggressive attempts at correction with blood products indicates that you have not corrected the problem or have missed a problem. Go back and completely re-evaluate the patient from square one.

Advanced Continuous Monitors

Currently, new monitoring technology is being pushed into the combat environment. The Vigileo monitor has already been described, and is one of several devices that provide cardiac and volume data through analysis of the standard arterial pressure waveform. Near-infrared spectroscopy (NIRS)-derived tissue oxygenation (StO2) has been studied in Iraq and is currently being studied in the pre-hospital and hospital setting in Afghanistan. The devices look like a glorified pulse oximeter. They use near-infrared spectrum light beamed into muscle tissue (typically the thenar eminence) to directly measure the oxygenation of hemoglobin in the muscle bed. The oxygenation of the peripheral muscle bed has been shown to reflect global perfusion, and the early studies suggest it is as good as base deficit at detecting shock but has the advantage of being continuous and non-invasive (Fig. 31.7). Keep in mind that like base deficit, NIRS StO2 values must be used in the context of a

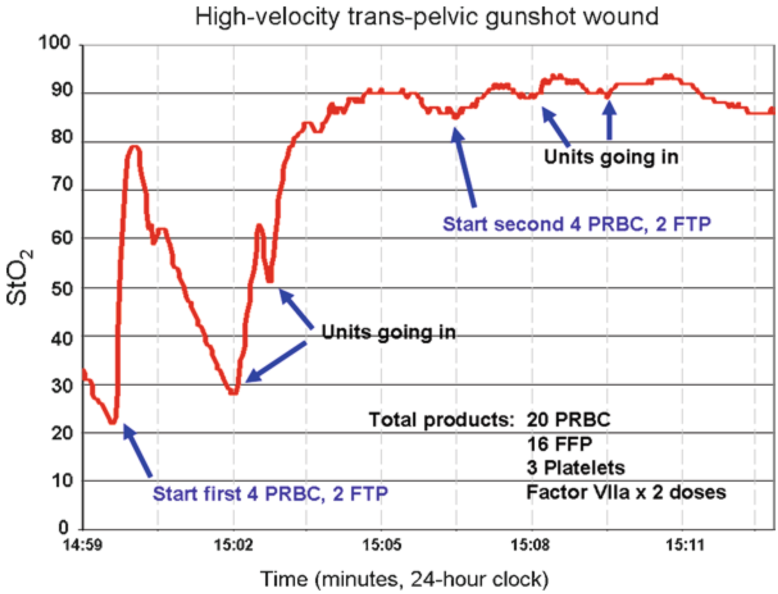

Fig. 31.7 Graph of Near-infrared spectroscopy (NIRS)-derived tissue oxygenation (StO2) data from a combat casualty in Baghdad. The StO2 data provided early recognition of initial severe injury, operative hemorrhage, and then the adequacy of the postoperative resuscitation

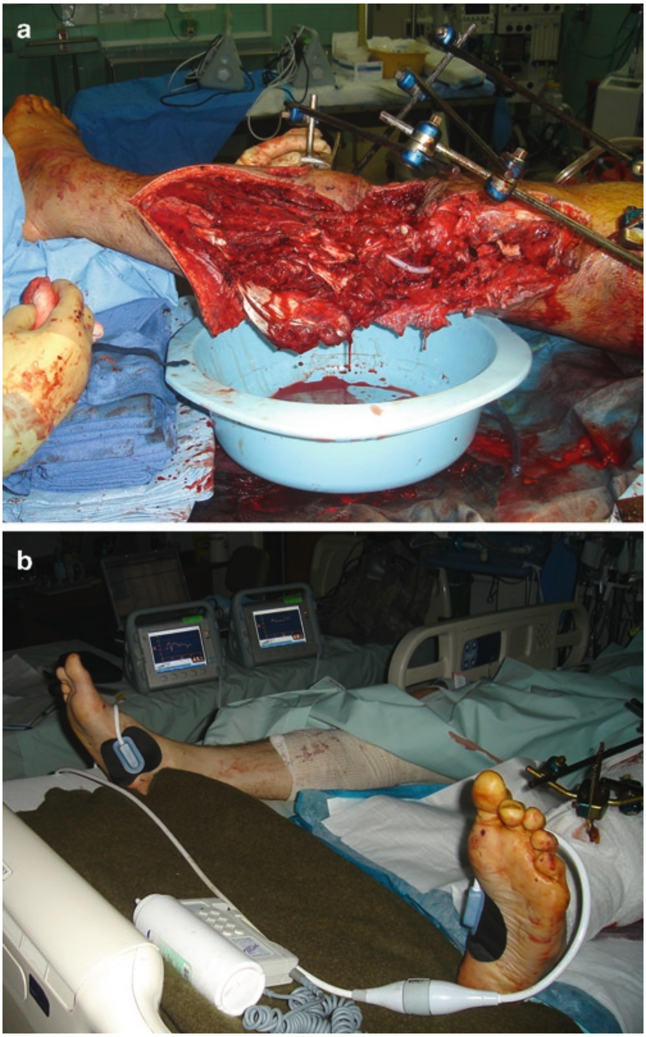

Fig. 31.8 (**a**) Casualty with severe left lower extremity wound and vascular repair; (**b**) The same patient post-operatively with near-infrared spectroscopy (NIRS)-derived tissue oxygenation (StO2) monitors placed on the injured extremity and on the uninjured extremity as a continuous monitor for graft thrombosis or compartment syndrome

casualty's clinical appearance. It is an additional data point among many, not a single reading on which you can hang your hat. In addition to being used as a global measure of systemic perfusion, NIRS StO2 may have great applicability to detect regional ischemia or compartment syndrome in extremity injuries after vascular repair (Fig. 31.8). Although the data are still being collected, the devices show some promise as potentially allowing early identification of vascular graft failure, compartment syndrome, and extremity ischemia.

Several other monitoring devices are being pushed into theater for study. Continuous monitors which can rapidly assess changes in pulse pressure and beat-to-beat variability in the heart rate (or R–R interval variability) have been deployed for continuous data stream collection on casualties for later analysis. Power spectral analysis is applied to the standard EKG tracing to assess the relative parasympathetic and sympathetic activity that is present, and thus the adequacy of autonomic compensation to the traumatic injury or insult. Preliminary data with this technology indicates that it can identify patterns that predict adverse outcome or death, primarily higher parasympathetic modulation and lower sympathetic modulation after injury. This could provide invaluable data from far-forward triage decisions all the way through to definitive operative care and postoperative monitoring. However, the reliability and accuracy of these newer measures remains to be demonstrated, particularly in the incredibly demanding and punishing climate of modern combat operations.

Closed-Loop Systems

Several standard monitors have been attached to elegant software programs to create a "closed-loop" system to guide critical decisions and interventions during resuscitation. Such systems, for example closed loop oxygenation, work by having a computer program adjust O2 concentration second-to-second based on the patient's O2 saturation. Similar closed-loop resuscitation programs have been created to adjust the IV fluid rate based on the patient's urine output and other vital signs. These technologies, while still being perfected, have been demonstrated to conserve resources and reduce over-treatment of casualties. They may be particularly useful in more austere settings where physician resources are limited or during MASCAL situations where personnel resources are overwhelmed. However, it must be emphasized that any of these systems will only be as good as the algorithms that guide them and the accuracy of the monitoring inputs that they utilize.

Summary

It is imperative that the deployed clinician understands that no monitor, lab, or study can replace his or her faculties and judgment. Monitoring devices and labs may provide useful data, but that data must be incorporated with all the other pieces of clinical data – a single data point should rarely, if ever, be acted on alone. The clinician should know the monitors available in his unit and the specific strengths and weaknesses of these particular devices and technology. There will be no shortage of new devices and technologies introduced with promises of providing "the answer" to all of your clinical dilemmas. As of now none of these can outperform the astute and experienced clinician at the bedside, integrating the important data points and filtering out the rest to best serve the wounded soldier.

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Chapter 32
Ventilator Management

A Practical Approach to Respiratory Failure in Combat Casualties

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Deployment Experience:

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BLUF Box (Bottom Line Up Front)

1. Acute lung injury (ALI) and acute respiratory distress syndrome (ARDS) are common in battlefield casualties, and are usually multifactorial in origin.
2. Blast lung injury is a common contributing mechanism to respiratory failure in recent conflicts. Management is similar to other etiologies of ARDS, and prognosis is excellent if patients survive their initial injuries.
3. Endotracheal intubation and mechanical ventilation should be initiated early in casualties with altered mental status or respiratory insufficiency, especially prior to transport.
4. Early application of positive end expiratory pressure (PEEP) is essential to maintain adequate lung recruitment and gas exchange.
5. Mucus plugs, pneumothorax and decreased lung compliance are common in combat casualties. A deliberate approach to mechanical ventilation trouble shooting is essential to accurately and rapidly address these problems.
6. Low tidal volume ventilation (≤6 cc/kg) improves mortality in ARDS. Airway pressure release ventilation (APRV) is the primary mode employed in theater to manage refractory hypoxic respiratory failure.
7. You are unlikely to have high level salvage modalities available (jet ventilation, inhaled nitrous oxide, etc.), so proper patient and ventilator management is critical!

(continued)

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BLUF Box (Bottom Line Up Front) (continued)

8. Don't attempt to "chase" a normal blood gas. Hypercarbia and moderate acidosis is fine and should not prompt increases in rate or tidal volume.
9. Think of every ventilator-delivered breath as harmful! Minimize the rate, the tidal volume, and the time on positive pressure ventilation as much as possible.

"Hypoxia not only stops the motor, it wrecks the engine.

Unknown

Increased use of body armor, the deployment of increased numbers of soldiers skilled in basic and advanced trauma life support, the presence of forward surgical teams (FSTs) and other innovations have significantly improved the chances of combat casualty survival from the point of injury to definitive medical care. As a result, the patients that survive to be treated by deployed military medical personnel care at the battalion aid station, FST and combat support hospital (CSH) are frequently critically ill. Early and effective critical care management of these battlefield casualties is both possible and essential with the equipment available in the current combat medical environment, and can result in dramatic and successful outcomes when these fundamental principles are maintained throughout the medical evacuation system. You may or may not have an intensivist deployed with you, so all deploying physicians should be familiar with principles of respiratory failure and ventilator management.

The most common mechanism of injury in recent conflicts has been explosion, either from improvised explosive device (IED) or rocket and mortar attacks. Past studies have shown that compared to gunshot wound victims, casualties of explosions have a much higher prevalence of multiple injuries, with an excess of head and extremity injuries. The chest is the most common location of internal organ injury in this population, largely due to the blast effects. As a result, intubation and mechanical ventilation for airway protection and management of respiratory failure is common. The purpose of this chapter is to provide a practical overview to the logistics, management and trouble shooting of mechanical ventilation in these casualties.

Which Combat Casualties Need Mechanical Ventilation?

The basic indications for intubation and mechanical ventilation – airway protection and the inability to adequately ventilate and/or oxygenate – apply equally to the management of battlefield casualties. The combat environment frequently forces providers to rapidly evacuate patients to a higher echelon of care after initial stabilization due to security concerns, and manpower and resource limitations at or close to the point of injury. Patient monitoring, identification of progressive clinical deterioration, and definitive airway management during transport can be extremely difficult. In general, the presence of multiple injuries requiring significant, ongoing

Table 32.1 Combat injury patterns associated with intubation, mechanical ventilation

Airway protection
Decreased level of consciousness (Glasgow Coma Scale <8)
Significant head trauma, cognitive dysfunction following blast injury
Airway trauma, obstruction
Craniofacial, neck injury with risk for airway compromise (consider surgical airway)
Significant airway blood, secretions
Inability to ventilate, oxygenate
Thoracic, lung injury
Flail chest, pneumothorax (even despite adequate management with tube thoracostomy)
Penetrating thoracic injuries
Respiratory distress, oxygen requirements following blast injury
Increased intracranial pressure (ICP), Herniation syndrome
Airway protection, hyperventilation to decrease ICP
Multiple Injuries, Anticipated Surgical Management
Injuries requiring massive transfusion
Thoracic, abdominal, large soft tissue injuries
>1 prox imal amputation
Hypotension, hypothermia on presentation

resuscitation, a high clinical suspicion for future surgical management, and clinical evidence or symptoms of significant head, neck or chest trauma should result in a low threshold for definitive airway management (endotracheal intubation or surgical airway), consideration for tube thoracostomy and initiation of mechanical ventilation prior to patient movement (Table 32.1).

Respiratory Failure in Combat Casualties: The Role of Blast Lung Injury

Acute lung injury (ALI) and subsequent respiratory failure in severely injured combat casualties is common. ALI is defined as the presence of diffuse radiographic infiltrates that are not cardiogenic in origin combined with evidence of hypoxemia (a PaO_2/FIO_2 ratio <300); the term acute respiratory distress syndrome (ARDS) is applied to patients with these criteria and a PaO_2/FIO_2 ratio <200. The etiology of ALI and ARDS in combat casualties is usually multifactorial, and can be divided into early and late causes of respiratory failure following initial injury (Table 32.2).

Of these contributing clinical factors, blast injury is the least familiar to most deploying providers. Weapon detonation results in the rapid decomposition of explosive into gas, which eminates from the central blast site as a blast wave. Primary blast injury occurs when this wave hits the human body, and is related to the amplitude, rate of rise and duration of the blast overpressure as well as the proximity of the victim to the blast site. Blast waves also tend to be reflected and amplified in a closed space, leading to more potential damage. If you receive casualties from an indoor blast, be very wary as they are more likely to have airway and/or lung injury

Table 32.2 Causes of ALI/ARDS in combat casualties

Early
Systemic inflammatory response following multiorgan trauma
Aspiration, chemical pneumonitis
Thermal, inhalation injury
Transfusion related acute lung injury (TRALI)
Blast lung injury (BLI)
Fat emboli (long bone fractures)
Late
Ventilator associated pneumonia (VAP)
Ventilator associated lung injury (VALI)

that may take 12–24 h to manifest. Secondary blast injury can be caused by weapon fragments and other debris scattered at high velocity by the explosion. Victims also suffer further injury if the blast throws them against a stationary object, or due to burns, inhalation or crush injury that may occur from fires and structural collapse that follow the explosion (tertiary, quaternary blast injury).

Clinical manifestations of primary blast injury include tympanic membrane perforation, bowel contusion and perforation, brain axonal injury, and myocardial contusion. Blast lung injury (BLI) has been reported to be present in 70% of civilian victims of terrorist violence, and is likely even more prevalent in the combat environment. Lung manifestations include barotrauma (pneumothorax, pneumomediastinum) due to gross thoracic deformation, hemoptysis and pulmonary contusion due to alveolar disruption and intraparenchymal hemorrhage within the lung from the blast wave. The classic clinical presentation of BLI, described as a triad of respiratory distress, hypoxemia, and perihilar "bat wing" pulmonary infiltrates, is rarely seen in these authors' clinical experience in the current combat environment. Because its onset can frequently be delayed and its radiographic presentation is variable, it is difficult to determine the true prevalence of BLI in the critically injured combat casualty, or to differentiate its contribution from other potential etiologies.

Initiation of Mechanical Ventilation

The initial mode and settings selected to ventilate a combat casualty depend on available ventilator capabilities, likely underlying patient lung mechanics and other associated clinical conditions, and the experience and comfort of your staff. Managing a patient in respiratory failure in a combat environment requires a significant commitment of expertise, staffing and resources; most deployed units will not have the depth or breadth of ventilator management experience available at a stateside facility, and preparing for this capability requires a team approach led by an experienced respiratory therapist or physician. If your facility is not equipped to meet all three of these demands for an extended period of time, early evacuation to a higher level of care becomes the overriding priority after mechanical ventilation has been initiated.

Table 32.3 Common available mechanical ventilators and capabilities

Type	Description
Impact™ 754 Eagle	Compact transport ventilator Internal or external power; typical battery life 2–4 h AC, SIMV, CPAP modes Settings: Ventilation rate, inspiratory time (or 1:2 I:E ratio default), tidal volume, FIO_2, high and low limit pressure alarms Additional features: Sigh breaths, PEEP (maximum 20 cm H_2O), plateau pressure, manual breath trigger, automatic apnea back up rate Display: Peak, mean inspiration pressure display; set and delivered tidal volume http://www.jdhmedical.com/Impact/754TrainingPresentation.ppt http://www.usamma.army.mil/Impact_754.cfm
VersaMed™ *i*Vent 201	Compact ventilator with expanded functions Internal or external power, battery life 2–4 h AC (volume or pressure control), SIMV, adaptive bilevel, CPAP, PSV Settings: Ventilation rate, inspiratory time, flow, pressure, tidal volume or target pressure, FIO_2, PEEP (maximum 20 cm H_2O), trigger sensitivity, pressure support Additional features: Adjustable rise time, 100% O_2 suction, easy exhale, sigh breath parameters, adaptive flow, adaptive time, back up apnea ventilation Display: Airway pressure, total breath rate, I:E ratio, exhaled tidal volume, exhaled minute volume, peak flow, inspiratory time, electrical power source, battery level http://www.versamed.com/products_specs.cfm
Drager™ Evita XL	Advanced, multifunctional ventilator Internal or external power; limited battery life AC (CMV), SIMV, MMV, PCV, PSV, CPAP, APRV, ILV modes Settings: Ventilation rate, inspiration time, flow, and pressure, tidal volume or target pressure, FIO_2, PEEP, pressure support, rise time for inspiratory pressure, trigger sensitivity, alarms Additional features: plateau pressure and auto-PEEP measurement, automatic tube compensation, multiple others Display: Multiple graphic waveforms for patient-ventilator synchrony; peak, mean airway pressure; minute volume; O_2 concentration; breathing frequency; lung mechanics; multiple others http://www.drager.com/media/10/01/04/10010474/evitaxl_br_9051396_us.pdf

Table 32.3 lists the capabilities of three common mechanical ventilators found in the Army Combat Health Support System along with websites that provide additional training resources. Prior to deployment, medical providers should identify the specific in-theater ventilators and oxygen supplies that will be available, and ensure that the responsible respiratory therapists and biomedical maintenance technicians have received the training necessary to ensure continuous operation of this equipment and a consistent supply of oxygen.

Lessons Learned from a Senior Respiratory Therapist

Oxygen and mechanical ventilation are critical resources, and in a deployed environment all members of the critical care team need to take a collaborative approach to understanding and managing the technical details involved in the delivery of these interventions.

Equipment and Planning

- All respiratory therapists and biomedical technicians should receive specialized training to operate and maintain the Impact 754 Eagle transport ventilator, (POGS) portable oxygen generating system, and the Expeditionary Deployable Oxygen Concentrator System (EDOCS) model 120.
- Oxygen delivery in a combat zone may come from more than one source, and requires strict logistical coordination and training. For example: a facility may have an on-site EDOCS with back up POGS and an emergency compressed cylinder stock level to provide redundancy in the event of equipment and/or supply line failure. Proper maintenance of this system and monitoring the inventory of compressed oxygen are critical tasks, particularly the “E” cylinders used for transports. A strict system establishes stock levels, properly labeling and segregates empty and full cylinders with daily counts and reports are good management goals.

Maintenance

- The “EAGLE” 754 IMPACT transport ventilator is currently the choice at Combat Surgical Hospitals. The “Achilles heel” of this ventilator is the lead-acid internal battery, which quickly loses efficiency in hot climates. These batteries can have a life span of 1 year in normal conditions provided regular battery maintenance is performed, and ventilators are stored in a temperature controlled environment when not in use. A properly trained biomedical technician should verify battery age and condition before placing a ventilator into service, and “stand by” ventilators for on air evacuation should be plugged in continuously to maintain a full charge. Placing a high priority on battery maintenance for ventilators and other transport equipment will minimize the risk of in-flight equipment failure, and dramatically improve patient safety during transport.
- Types and models of ICU ventilators can vary widely by facility in theater. The ability to obtain replacement parts for these ventilators are key issues, and maintaining a backup stock of parts is a good idea to ensure continuous availability.

Patient Care

- Clinical practice in a combat zone is only limited by your resources and experience. Developing sound fundamental practices at the outset will ensure your RTs can perform to expectations. Readily available evidence based guidelines are great references to develop “in theater” SOPs for daily operations.
- Air evacuation: Staffing air evacuations with first time participants is common. Sight and hearing is very limited in a rotary winged aircraft, and maximizing patient monitoring with continuous ECG, blood pressure, pulse oximetry and end-tidal CO_2 when available is vital. Feeling for pulses and checking the rise and fall of the chest can confirm circulation and ventilation if all else fails. Always travel with airway supplies within reach, including a bag valve mask, suction, and oral airways. Be organized and familiar with all equipment, particularly the change out procedure for an oxygen tank connected to the ventilator.
- Be prepared to treat a wide variety of patients and conditions, including the ability to treat neonates, children and adults.
- The ability to secure endotracheal tubes for patients with facial burns and trauma is vital. Be sure to have several types of ET tube securing devices to give the clinician options.
- Mucus plugging is common in the dry desert environment, especially in pediatric patients. HMEs are frequently inadequate to address this issue, and heated humidifiers are a must for any patient who is likely to remain intubated for more than 24–48 h.

Helpful References

http://www.usamma.army.mil/homepage.cfm

http://www.usamma.army.mil/assets/docs/startup/6530-01-533-4481_GENERATOR%20OXYGEN%20MEDICAL%20SYSTEM%20POGS_HANDBOOK_INSERT_STARTUP_111808.pdf

http://pacificconsolidatedindustries.com/index.php?option=com_content&task=view&id=108&Itemid=71

Initial ventilator settings should take into account the patient’s clinical situation and the expertise and experience of the medical provider and his/her staff. Most trauma casualties have received a significant physiologic insult, and are at risk for rapidly progressive acute lung injury. As a result, our bias is to initiate the patient on a controlled ventilation mode (assist control, AC) to allow the ventilator assume most or all of the work of breathing. Typical ventilation settings include a respiratory frequency of 12–15 and a tidal volume of 6–8 cc/kg, to equal a minute ventilation of 8–10 L/min. Tidal volumes can be reduced as necessary to maintain a plateau pressure <30 cm H_2O (Fig. 32.1; use peak pressure if plateau pressure is not available),

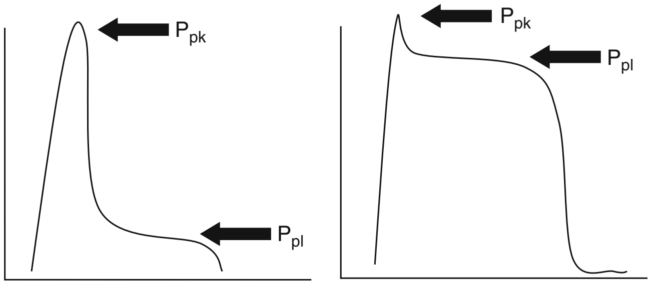

Fig. 32.1 Measurement of the plateau pressure is performed during an inspiratory pause maneuver, and provides an estimate of the pressure transmitted at the level of the alveoli. Ppk = peak inspiratory pressure, Ppl = plateau pressure. Graphic demonstration of a large peak to plateau gradient, seen in the setting of bronchospam, mucus plugging, or a kink in the endotracheal tube (*left*). A small peak to plateau gradient (*right*), which may be seen in the setting of decreased lung compliance (i.e. ARDS), a large pleural effusion or tension pneumothorax, or abdominal compartment syndrome

Table 32.4 Ventilator adjustment tips and pearls

General approach
Consider every ventilator-delivered breath as causing additional lung injury
Use the lowest respiratory rate and tidal volume needed
Minimize exposure to the ventilator – extubate whenever possible
Pulmonary function and compliance are dynamic – re-evaluate and adjust frequently
Avoid "chasing" the blood gas – don't make vent changes just to get "normal" numbers
Dys-synchrony ("fighting the vent") will often respond to ventilator adjustments to improve the comfort of breathing rather than more sedation or paralysis
Oxygenation
Use as much oxygen (up to 100%) as you need initially to avoid hypoxia, but….
Avoid prolonged periods of high FIO_2 – use PEEP and adjuncts to wean to 30–40%
You do not need a PaO_2 of 400. A PaO_2 of 60–80 is acceptable
Hypoxia = mucous plugging, pulmonary embolus, ventilator problem, or ARDS
Adjustable factors that drive oxygenation are: PEEP, FIO_2, and mean airway pressure
Ventilation
Accept elevated pCO_2 levels as long as the pH is above 7.2
Acute and large changes in pCO_2 = embolus, cardiac event, ventilator malfunction
Adjustable factors that determine ventilation (pCO_2) are respiratory rate and tidal volume
Respiratory acidosis may be a response to a metabolic alkalosis (and vice-versa) – correct the metabolic process and the ventilation will correct itself

with small increases in respiratory rate to maintain an appropriate minute ventilation. Initial FIO_2 levels of 100% are rapidly reduced to maintain a SaO_2 level >93%, and PEEP can be increased by 3–5 cm H_2O increments to keep the FIO_2 <60%. See Table 32.4 for some ventilator adjustment pearls.

There are certain clinical issues specific to mechanical ventilation in trauma patients that are commonly discussed. These clinical pearls can be summarized in the following points:

- Neurotrauma: Patients with head trauma should be ventilated with the goal of maintaining adequate oxygenation and a normal CO_2 level to allow for normal cerebral perfusion and oxygen delivery. Hyperventilation (target pCO_2 28–30 mm Hg) is an effective short term therapy to reduce elevations in intracranial pressure (ICP) through cerebral vasoconstriction and a reduction in intracerebral blood volume until other definitive measures can be taken. Minute ventilation should slowly be decreased following definitive ICP intervention to restore adequate cerebral perfusion, with close ICP monitoring between changes. Avoid hypercarbia (pCO_2>40)!
- ARDS: Low tidal volumes(≤6 cc/kg, decreased as necessary to keep the plateau pressure <30 cm H_2O) have been shown to reduce mortality in ARDS by almost 9% and reduce potential ventilator associated lung injury. This is typically combined with a high PEEP strategy, which has been shown in clinical trials to improve oxygenation.
- Barotrauma: High levels of PEEP can lead to persistent leak in the setting of bronchopleural fistula; lower levels or 0 cm H_2O of PEEP are generally recommended, even if higher FIO_2 requirements are necessary to maintain adequate oxygenation.
- Flail chest: Although higher levels of PEEP may theoretically improve pain from mechanical dys-syncrony from multiple contiguous rib fractures, the clinical impact of this intervention is far outshadowed by the beneficial effect of an early thoracic epidural.
- Abdominal compartment syndrome: Progressive increases in peak inspiratory pressure with a minimal peak to plateau pressure gradient in the setting of significant abdominal distention should raise clinical concern for an abdominal compartment syndrome.

Troubleshooting Common Ventilator Problems

Hypercapnea and Respiratory Acidosis

Hypercapnea can occur when CO_2 production increases without a corresponding increase in alveolar ventilation, or due to a reduction in alveolar ventilation alone. Decreases in minute ventilation due to changes in mechanical ventilator settings are common. CO_2 can also rise in the setting of low tidal volume ventilation even with high minute ventilation, typically due to dead space increases. Other causes of hypercapnea include sudden increases in dead space due to a massive pulmonary embolism, a leak in the ventilator circuit or other more severe cases of ventilation/perfusion mismatch.

The first step when faced with sudden, unexpected hypercarbia is to check the patient's minute ventilation. If the minute ventilation is significantly reduced from prior, the ventilator settings should be checked to ensure that no inadvertent changes have occurred, the patient should be suctioned to exclude new, significant mucus plugging, and a chest x-ray performed to exclude new significant intrathoracic abnormalities. If these steps do not reveal an adequate explanation, careful evaluation for developing sepsis (with increasing metabolic demand resulting in increased CO_2 production) or pulmonary embolism should be considered.

Respiratory acidosis is a common complication during low tidal volume ventilation for ARDS. Permissive hypercapnea is an accepted practice in this setting, unless there is concomitant head trauma with significant elevations in ICP. There remains no significant evidence to date that elevated levels of CO_2 have any clinical adverse effects, and may be protective against further lung injury. Continuous pH levels <7.0–7.1 can result in decreased effectiveness of vasopressor therapy and increased risk of arrhythmia in critically ill patients; bicarbonate or THAM infusion should be used to maintain pH >7.2 but beware that bicarbonate can worsen acidosis if minute ventilation is inadequate.

Hypoxemia and ARDS

Hypoxemic respiratory failure on the battlefield is a common problem, and severe or rapidly progressive cases should be evacuated early to higher echelons of care before transport personnel face a situation where they are unable to deliver adequate amounts of oxygen and positive end expiratory pressure at altitude to maintain the patient during transport.

The differential diagnosis of hypoxemic respiratory failure in combat is listed in Table 32.5. The most common cause of persistent hypoxemic respiratory failure in combat is ARDS, and adoption of a low tidal volume, high PEEP mechanical ventilation strategy to reduce mortality and ventilator associated lung injury and improve oxygenation has been discussed above at length. Management of refractory hypoxemic ARDS despite this ventilator strategy is challenging in modern U.S. hospitals, and many largely unproven salvage therapies employed for these patients (inhaled nitric oxide, high frequency ventilation) are not available in combat. The clinical approach to the management of these patients in the combat environment depends on the resources available, especially in light of the harsh reality that survival in these cases is poor regardless of the clinical setting (Fig. 32.2).

Table 32.5 Common causes of hypoxemic respiratory failure in combat

Pneumothorax
Pulmonary embolism
Obstructive lung disease exacerbation (asthma, COPD)
ALI/ARDS (see Table 32.2)
Congestive heart failure
Mucous plugging

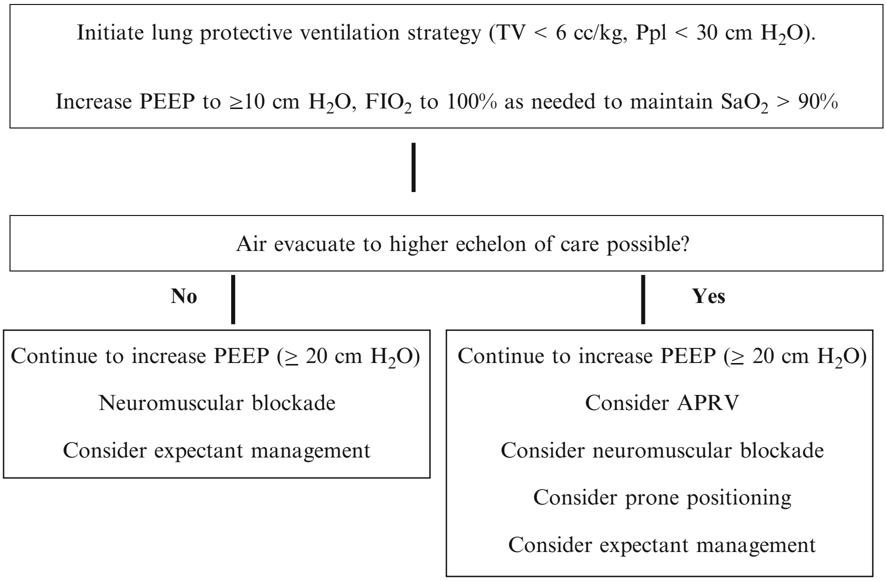

Fig. 32.2 Algorithmic approach to ARDS with refractory hypoxemia in combat trauma patients

Any patient requiring high levels of oxygen and a PEEP of ≥10 cm H_2O after initiation of mechanical ventilation will clearly require more than a brief period of intubation, and should be expeditiously evacuated to a higher level if possible. This is easy for U.S. soldiers but not an option for most civilians or local nationals. There are no upper limits to PEEP (although pressures >20 cm H_2O will reduce systemic venous return and cardiac output without continued additional fluid administration), and neuromuscular blockade can improve patient ventilator synchrony and reduce metabolic oxygen demands that may allow for improvements in oxygenation. Patients without improvement following these interventions should be managed expectantly.

If your patient is failing with a conventional ventilation mode, then a salvage therapy should be attempted. The most common salvage mode employed in theater is airway pressure release ventilation (APRV), a pressure targeted mode of ventilation that keeps the lung inflated for the majority of the respiratory cycle. Based on its settings, the ventilator will periodically "release" its pressure for a fraction of a second before returning to its previous pressure setting to allow for ventilation (Fig. 32.3). A unique feature of APRV ventilation is that the circuit allows the patient to spontaneously breathe over this set waveform, which provides increased minute ventilation, further improvements in alveolar recruitment, and better patient comfort. Standard initial ventilator settings using this mode is a high pressure (P_{High}) of 30 cm H_2O, a low pressure (P_{Low}) of 0 cm H_2O, a time at the high pressure (T_{High}) of 3.5 s and a time at the low pressure (T_{Low}) of 0.8 s with an FIO_2 of 100%. Further improvements in oxygenation can be achieved by increasing the P_{High} and/or T_{High}. A common mistake is ramping up the P_{Low} thinking that this is equivalent to adding PEEP – in general you should leave the P_{Low} at zero.

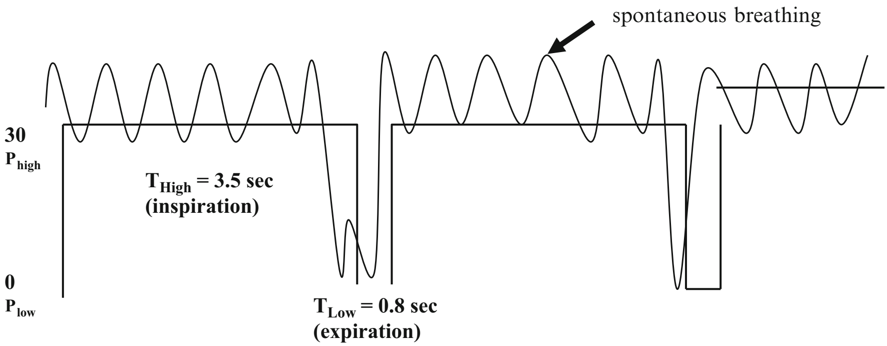

Fig. 32.3 A pressure/time curve demonstrating APRV (airway pressure release ventilation) mode in a spontaneously breathing patient

Early and aggressive implementation of APRV ventilation can frequently obviate the need for further salvage strategies for refractory hypoxemia in ARDS. Another potential salvage strategy is prone positioning, which increases effective ventilator pressure transmission to the lungs and improves ventilation perfusion matching by positioning the patient supine. Prone positioning is effective but it is extremely labor intensive and can be dangerous in unskilled hands due to the risk of inadvertent device removal and inadequate protection of sensitive pressure points. Ensure all tubes (especially the airway) are secured and the patient is adequately padded in the prone position. Start an alternating cycle of proning for 4–6 h intervals. Document the improvement in the P:F ratio for each proning cycle and cease proning when the degree of improvement in P:F in the prone position has decreased (less than 10–20%). Only use this in relatively stable patients as you will not have access to their chest for CPR or other emergent interventions.

Final Points

Effective trauma care has increased the number of critically ill patients that survive their initial injuries and present to combat medical providers for care. Early intubation and mechanical ventilation is essential during ongoing damage control and resuscitation efforts, and when employed correctly can support the majority of patients with ALI and ARDS from blast injury and other insults to recovery. Providing mechanical ventilation on the battlefield is a complex proposition, and requires coordination and training a multidisciplinary team of providers, respiratory therapists, nurses and biomedical technicians to ensure seamless, continuous care.

Chapter 33
Practical Approach to Combat-Related Infections and Antibiotics

Clinton K. Murray

Deployment Experience:

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BLUF Box (Bottom Line Up Front)

1. Evacuate to surgical care within 6 h.
2. Aggressively debride wounds with removal of all necrotic tissue and foreign bodies easily reached except in the eye, brain, and spine.
3. Irrigate wounds until clean with normal saline or sterile water without additives under low pressure (less than 14 PSI).
4. Infuse antibiotics within 3 h of injury; avoid overly broad spectrum antibiotics and minimize duration; antibiotic activity should best reflect the most contaminated site; IV infusion of antibiotics is preferred.
5. Give tetanus immunoglobulin and toxoid as appropriate.
6. Do not obtain routine pre- or post-procedure microbial cultures; obtain cultures only when there is clinical evidence of infection.
7. Extremity wounds should undergo delayed primary closure; skin should not be closed if there is a colon injury or extensive devitalized tissue due to excessive infectious complications.
8. If no evacuation at 3–5 days; consider closing wounds if no evidence of infection.
9. All forward hospitals are breeding grounds for resistant organisms. It's not the soil, or the projectiles, or the water…it's your facility!

Every operation in surgery is an experiment in bacteriology.

Berkeley Moynihan (1865–1936)

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It was not long after military casualties from the wars in Iraq and Afghanistan began filtering back into medical centers throughout the United States that whispered talk began of a bacterial “superbug” that wounded soldiers were carrying back with them from the front lines. A series of strange infections with resistant (but still Imipenem susceptible) acinetobacter surfaced on a Navy hospital ship, the US Comfort, in 2003. This was followed by outbreaks at military medical facilities in the USA, the level IV evacuation hospital in Landstuhl, Germany, and many civilian hospitals that accepted wounded veterans. What was more concerning what that many of these outbreaks were now found to be caused by a strain of highly resistant acinetobacter, even to the big guns of Imipenem. Rumors circulated that this bug was endemic in the soil and water of Iraq, and was being blown into the wounds by improvised explosive devices. The truth was much simpler: they were catching this “superbug” at our forward military surgical hospitals, like the Ibn Sina facility in Baghdad. The lesson learned here is that even in a “mature” theater of combat operations, the combination of severe wounds with infected and dead tissue, less than ideal sterility conditions, and widespread (and uncontrolled) use of antibiotics is a recipe for infectious disease problems. Some of these factors are beyond your control, but many of them are modifiable behavioral and practice patterns that you and your colleagues can adapt to minimize the chances of your patients becoming another statistic or cautionary tale.

Introduction

Infections have complicated the care provided to those wounded in war throughout recorded history. During Operation Iraqi and Enduring Freedom (OIF/OEF), approximately one-third of casualties develop an infectious complication with sepsis being the fourth most common cause of reversible mortality. Infectious risks associated with combat-related injuries include those from initial wound contamination and from nosocomial infections associated with long-term care. The latter often involve multiply drug resistant bacteria (multidrug-resistant organisms, MDROs) such as the gram negative bacteria *Acinetobacter baumannii, Pseudomonas aeruginosa,* extended spectrum beta-lactamase producing *Escherichia coli* and *Klebsiella pneumoniae,* and the gram positive bacteria methicillin-resistant *Staphylococcus aureus* (MRSA).

The most comprehensive treatment strategies for managing combat-related injury infections can be found in the *Emergency War Surgery Manual* (Borden Institute) and the guidelines developed by the US Army and published in the *Journal of Trauma* (2008;64:S211). These publications highlight different injury patterns with evidence-based weighting of recommendations. The suggestions provided in this chapter for preventing and treating combat-related infections are obtained from those guidelines along with the recommendations by the Tactical Combat Casualty Care (TCCC) committee. Of note, the recommendations are not for managing nosocomial infections. In addition, it is vital to recognize the importance of infection control – even in a combat setting – and that it begins during the initial stages of stabilizing a patient. Overall, surgeons should attempt to replicate standard US surgical care with dedicated operating rooms, good hand hygiene, wear of new scrubs with hats and shoe covers in the OR, adequate cohorting of infected patients, protocols for disinfection and/or sterilization of patient care equipment, and appropriate environmental cleaning.

The primary method to prevent the development of infection in penetrating trauma is rapid surgical evaluation and management without relying on antimicrobial therapy to “sterilize” the wound. This is a lesson that has been repeatedly relearned since antibiotics have been available on the battlefield. Treatment strategies vary by anatomical location; however, overall treatment strategies include an emphasis on irrigation, debridement, antimicrobial therapy, coverage of wounds, and stabilization of underlying bony structures. Other interventions of secondary importance include minimizing blood transfusion, controlling hyperglycemia, minimizing hypothermia, and providing adequate oxygenation. In addition, antibiotic control programs should be put in place in the combat zone to limit use of broad spectrum antimicrobial agents. It is critical to get your entire hospital team involved in infection control measures and to understand that “appropriate” antibiotic use often means narrowing the coverage or stopping antibiotics altogether.

Prevention of Infection

Care at Point of Injury (Level I)

Initial care provided in the combat zone near or at the time of injury should emphasize safety of the patient and the personnel caring for the patient, controlling hemorrhage, and stabilization of breathing and airway per TCCC. Wound care at this point consists of wound coverage with sterile bandage and stabilizing bony structures with rapid evacuation to a surgeon within 6 h if possible. If evacuation to surgical care is expected to be longer than 3 h, antibiotics should be provided to the casualty as soon as possible (Table 33.1). The selection of these agents is based on spectrum, ease of

Table 33.1 Antimicrobial therapy for prevention of infection in combat-related trauma during the care of casualties under tactical situations when evacuation is expected to be delayed (>3 h)

TCCC	Preferred agent	Alternate agent	Duration
Open extremity wounds	Moxifloxacin 400 mg PO	Levofloxacin 500 mg PO	One dose
Penetrating abdominal injury, shock, or unable to tolerate oral medication	Ertapenem 1 g IV/IM	Cefoxitin 2 g IV/IM	One dose

Tactical Combat Casualty Care (TCCC). The three phases of TCCC in which these antibiotic choices apply are “Care Under Fire” which is the care rendered by the medic or first responder at the scene while still under effective hostile fire, “Tactical Field Care” which is care rendered by the medic once no longer under effective hostile fire and medical equipment is still limited, and “Combat Casualty Evacuation Care” which is the care rendered once the casualty has been picked up by evacuation vehicles but has not reached a higher level of care including a Battalion Aid Station (BAS) or Forward Surgical Team (FST) administration, stability, and storage limitations. These antibiotic recommendations are not applicable to patients who can be rapidly removed from the battlefield or to those who have reached care at established medical facilities such as a battalion aid station (BAS) or Combat Support Hospitals (CSH). Based on mission, oral moxifloxacin has been placed into some personal medical kits (that also hold individual use items such as tourniquets, bandages, and pain medications) along with medic/corpsman medical kits.

Professional Medical Care Without Surgical Support (Levels I and IIa)

Care at a BAS (Level I) is typically provided by a physician assistant and/or a general medical officer with no patient holding capability. Patients are evacuated from these facilities within 1–2 h of injury in Iraq, with slightly longer delays in Afghanistan. Although enhanced casualty care can be provided, the primary goal for most injuries is stabilization and evacuation to a surgeon within 6 h of injury. Primary wound management consists of wound irrigation with removal of gross contamination. Wounds should be bandaged with a sterile dressing and underlying bony structures stabilized to prevent further injury. Antibiotics, typically intravenous, should be given within 3 h of injury (Table 33.2). The agent of choice should reflect the injury site requiring the broadest spectrum of bacterial activity; avoiding excessively broad empiric antimicrobial therapy. Tetanus immunoglobulin or toxoid should be given as indicated. It is acceptable to leave small, retained metal fragments in soft tissues; however, x-ray evaluation is necessary to adequately determine location and extent of injury.

Care with Surgical Support (Levels IIb and III)

Surgical care provided in the combat zone is available at Level IIb facilities (Forward Surgical Teams), which are designed for damage control surgery and short-term holding of patients, and Level III facilities (Combat Support Hospitals) which provide tertiary referral care in the combat zone. Although casualties should be evaluated by a surgeon within 6 h of injury, there is no requirement for surgery to occur within that time window.

There is no indication for pre- or post-procedure microbial cultures at initial surgery. Even at subsequent debridement, unless there is gross evidence of infection, wound cultures do not adequately predict subsequent infections or infecting pathogens. Inappropriately obtained wound cultures may lead to unnecessary courses of antibiotics, even broad spectrum ones.

Aggressively debride wounds at initial surgery. Skin should rarely be closed due to excessive infectious complications. For abdominal injuries, debride all non-viable

Table 33.2 Selection and duration of antimicrobial therapy for prevention of infection in combat-related trauma

Injury	Preferred agent(s)	Alternate agent(s)	Duration
Skin, soft tissue, bone			
Skin, soft tissue, no open fractures	Cefazolin, 1 g IV q8h	Clindamycin 900 mg IV q8h	72 h
Skin, soft tissue, with open fractures, exposed bone, or open joints	Cefazolin 1 g IV q8h[a]	Clindamycin 900 mg IV q8h[a]	72 h
Thoracic cavity			
Penetrating chest injury, with chest tube	Based on wound (see skin, soft tissue above)	Based on wound	NA
Abdomen			
Penetrating abdominal injury with suspected/known hollow viscus injury and soilage	Antibiotics with broad spectrum activity, including anaerobic activity. Options include cefoxitin 1–2 g IV q6–8h, or piperacillin/tazobactam 4.5 g IV q6h	Levofloxacin 750 mg IV once daily, or ciprofloxacin 400 mg IV q8–12h AND metronidazole 500 mg IV q6h, OR moxifloxacin 400 mg IV (monotherapy)	24 h after definitive cleaning
Maxillofacial			
Open maxillofacial fractures, or maxillofacial fractures with foreign body or fixation device	Cefazolin 2 g IV q8h (higher dose recommended because of failures at 500 mg)	Clindamycin 900 mg IV q8h	24 h
Central nervous system			
Penetrating brain injury	Cefazolin 1 g IV q8h. Consider extending bacterial activity if gross contamination. Options included cefazolin AND gentamicin AND penicillin	Ceftriaxone 2 g IV q24h. Consider extending bacterial activity if gross contamination. Options include cefazolin AND gentamicin AND penicillin. For penicillin allergic patient Vancomycin 1 g IV q12h and ciprofloxacin 400 mg IV q8–12h	5 days
Penetrating spinal cord injury	As above. Add anaerobic bacterial activity if abdominal cavity is involved. Options include metronidazole 500 mg IV q6–8h	As above. Add anaerobic bacterial activity if abdominal cavity is involved. Options include metronidazole 500 mg IV q6–8h	5 days

(continued)

Table 33.2 (continued)

Injury	Preferred agent(s)	Alternate agent(s)	Duration
Eye			
Eye injury, burn or abrasion	**Topical:** Erythromycin or Bacitracin ophthalmic ointment QID and PRN for symptomatic relief **Systemic:** No systemic treatment required	Fluoroquinolone one drop QID	Until epithelium healed (no fluorescein staining)
Eye injury, penetrating	Prior to primary repair, no topical agents should be used unless directed by ophthalmology	Levofloxacin 750 mg IV/PO once daily	3–5 days
Burns			
Burns	**Topical:** Large full thickness and contaminated burns should be treated with mafenide acetate once daily (mornings) and silver sulfadiazine once daily (afternoons) **Systemic:** No systemic treatment required	Mafenide acetate or silver sulfadiazine to wounds twice daily. More limited (clean) full thickness burns may be treated with silver-impregnated dressings. Biobrane can be used in partial thickness burns	

[a]These guidelines do not advocate adding enhanced gram-negative bacterial activity in type III fractures (ciprofloxacin 400 mg IV q8h or amikacin 15–20 mg/kg IV once daily)

solid and hollow viscera and drain most solid organ (i.e., liver and pancreas) injuries. Small wounds to a hollow viscus may be primarily repaired. The combat surgeon should be appropriately apprehensive with destructive colon injuries that require resections and anastomosis. Diversion should be considered in cases of colon injuries that require resection, particularly in the multiply injured or transfusion-requiring patients. Appropriate antibiotics (Table 33.2) should be administered perioperatively, but the common practice of continuing them for days in cases of gastrointestinal injury is of no benefit, and likely harmful. Perioperative antibiotics in general are for 24 h; after that antibiotic use should be based on standard infectious indications.

Certain injuries, notably the eye, spine, and brain, have a higher associated morbidity with immediate surgical intervention by an untrained subspecialist that outweigh the infectious complications, limiting benefits of immediate debridement. Whenever possible, evacuate these patients to a facility with ophthalmologic and/or neurosurgical expertise.

Irrigate wounds copiously. For extremity injuries, 3 L of fluid are typically used for type I fractures, 6 L for type II fractures, and 9 L for type III fractures. For other wounds the recommendation is irrigation until the wounds are “clean,” which is typically 6 L for abdominal injuries. The recommended irrigation fluids are normal saline or sterile water but potable water is acceptable with delivery under low pressure (typically less than 14 PSI). Recent tissue and microbiologic data has implicated the use of high pressure irrigation systems (i.e. pulse lavage) in delayed wound healing and higher rates of wound infection.

Give antibiotics as soon as possible following injury and intravenously within 3 h of injury. Use agents that should cover the pathogens likely to be contaminating the wounds at the time of injury; these may include normal cutaneous and enteric flora such as *Staphylococcus*, *E. coli*, and alimentary tract anaerobes. You should NOT direct initial antibacterial activity at multi-drug resistant organisms (MDROs) such as *Acinetobacter baumannii*, *Pseudomonas aeruginosa*, or *Klebsiella pneumoniae* as they are not typically recovered in the wound at the time of injury. Given the low number of MRSA infections, along with research which favors drainage over antibiotics as the primary therapy of MRSA skin and soft tissue infections, empiric MRSA therapy with vancomycin is rarely necessary. Agents should be active against the injury that requires the broadest spectrum of bacterial activity. There are data that suggest the use of broad spectrum antibiotics often leads to the development of subsequent infection with resistant pathogens. In addition, research from the United Kingdom indicates even penicillin-based regimens are adequate for extremity injuries. The duration of antibiotic therapy should be minimized as indicated in the Table 33.2. Prolonged therapy has been shown to worsen outcomes. Antibiotics should not be used just because the wound is “open” or because a drain, including a chest tube, remains in place. The role of topical antimicrobial therapy is clear for burn patients. Antibiotic impregnated beads for open fractures may be an appropriate therapy for personnel not being evacuated out of the combat zone who will also have an appropriate follow up. Their role is not clear for US personnel being evacuated 1–3 days after injury. Burn patients do not require systemic antibiotics unless there is evidence of infection or if antibiotics are indicated for treatment of other injuries.

Combat wound management includes delayed primary closure for extremity wounds; however, injuries to the face and brain require early closure of the mucosal lining or dura to decrease infections. Vacuum-assisted closure (VAC) has been shown to be effective for personnel not being evacuated out of the combat zone when used in extremity and abdominal injuries. Remember that localized soft-tissue infections that are adequately opened and drained (or undergoing VAC therapy) do not require prolonged antibiotics unless there are systemic manifestations of infection.

Stabilization of underlying bony structures helps prevent subsequent infections. External fixation is recommended for extremity wounds; however, there are infectious complications with percutaneously placed pins necessitating close clinical monitoring.

Patients requiring splenectomy should receive immunization against encapsulated organisms (e.g., *Haemophilus influenzae*, pneumococcal and meningococcal vaccines), ideally at 14 days of injury as this provides optimal immune reconstitution. However, you are better off administering vaccinations while the patient is under your control rather than counting on someone else to do it further along the evacuation chain. Administer them prior to discharge from your facility. Also, advise the patient about seeking immediate medical attention for any signs of symptoms of infection and the need for routine influenza and pneumococcal vaccinations.

Care of Personnel Not Evacuated Rapidly Out of the Combat Zone

There is a large non-US patient population receiving damage control surgery and definitive therapy without evacuation to higher levels of care. Manage these patients according to criteria based upon nosocomial (not community-acquired) infections after admissions of greater than 72 h. These patients may be at significant risk for MDRO colonization and infection due to prolonged admission, especially if aggressive infection control procedures are not followed. In the combat zone, evaluate these patients for signs and symptoms of infection and culture for bacteria appropriately. Therapy should be pathogen specific based upon culture results and antibiotic resistance testing if available. Direct empiric therapy by the facilities antibiogram, which should be updated regularly.

Implement comprehensive management strategies for the prevention of nosocomial infections as is done in US military treatment facilities. This should include infection control procedures and aggressive antibiotic control programs. Every facility, no matter the size, should have at least a designated infection control officer, and preferably an infection control committee. Remember the simple but high yield interventions such as hand-hygiene reminders, traffic control in high acuity areas (Intensive Care Unit, burn units), and the checklist approach to daily goals in the ICU (see Chap. 29). Figure 33.1 shows the impact that a simple targeted program

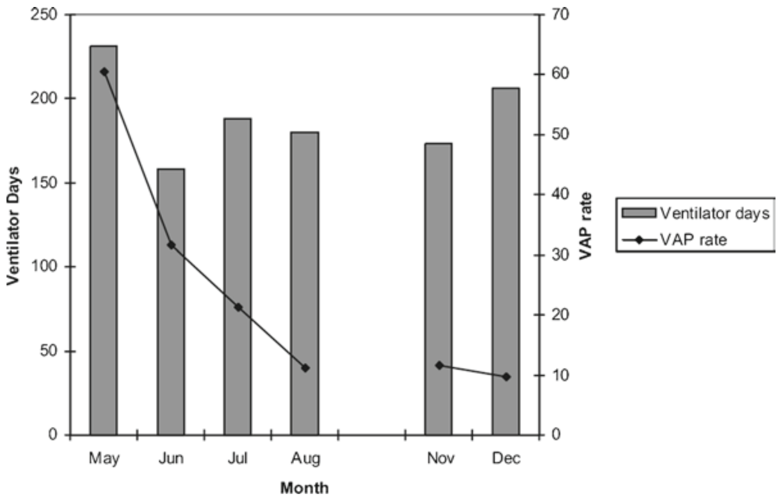

Fig. 33.1 Graph showing the sharp decline in rates of ventilator associated pneumonia (line with circles) at the Air Force Theater Hospital (Balad, Iraq) after implementation of a targeted infection control program. The VAP rate is expressed as the number of infections per 1,000 ventilator days (reprinted with permission)

of awareness and infection control had on the rates of ventilator-associated pneumonia at the Air Force Theater Hospital in Iraq. This can be accomplished in combat hospitals!

Final Points

Despite the fact that bombs and bullets are the most common images associated with war casualties, infection will be one of the top three killers in any combat medical facility. These common complications of combat-related injuries necessitate a multi-faceted approach to management including irrigation, debridement, coverage of wounds, and stabilization of underlying bony structures. Use antimicrobial therapy as an adjunct to these strategies; do not rely upon antibiotics to sterilize a wound. Tailor antibiotics to the injury site, avoid overly broad-spectrum coverage, and use the agents for a limited period of time after initial injury. If a patient develops a nosocomial infection, choice of antibiotics should be dictated by recovery of a pathogen associated with the infection and its resistance pattern. Fundamental to preventing subsequent infections with MDRO is aggressive infection control strategies in and out of the combat zone. Be a leader in infection control and management, and encourage others by your example. You CAN and WILL make a difference.

Chapter 34
Stabilization and Transfer from the Far Forward Environment

Shawn C. Nessen

Deployment Experience:

Shawn C. Nessen General Surgeon, 28th Combat Support Hospital, Baghdad, Iraq, 2003
Commander, 541st Forward Surgical Team (Airborne), Orgun-E, Afghanistan, 2006–2008

BLUF Box (Bottom Line Up Front)

1. Build an effective ATLS and Surgical Team.
2. Clearly define personnel roles.
3. Stop the bleeding and keep the patient warm!
4. Resuscitate the patient! Prevent crystalloid over-resuscitation.
5. The key to successful far forward surgery is doing the least amount of surgery possible to stabilize the patient.
6. Early transfusion of packed red blood cells (PRBC) and fresh frozen plasma (FFP) at a 1:1 ratio prevents coagulopathic bleeding and acidosis and saves lives.
7. Warm fresh whole blood (WFWB) is used as a platelet substitute and should be given to patients requiring ten or more units of PRBCs.
8. WFWB takes one hour to obtain and FFP takes 30 min to thaw. You must anticipate the need for these products early and act appropriately.
9. Forward Surgical Teams may not have X-ray machines, but you can function without them!
10. The tactical situation impacts the decision to operate or not to operate as much as the clinical situation.
11. Develops and rehearse an effective forward operating base MASCAL plan.

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> *Good surgery must be done as far forward as possible. If it is too good, in the sense of too elaborately equipped, it will not be far enough forward, and if it is too far forward it will not be good enough.*
>
> William H. Ogilivie (1887–1971)

Incident Summary: "The patient arrived at the Forward Surgical Team (FST) site 30 minutes after being wounded in the right thigh. A tourniquet had completely arrested the bleeding from the injured superficial femoral artery. The surgeons at the FST decided to repair the artery onsite and the 3 hour surgery was reported to have gone well. The patient had received 4 units of packed red blood cells and a reverse saphenous interposition graft had been used to repair the injured superficial femoral artery. However, when the proximal and distal clamps were removed, the patient began to bleed profusely from all his wound sites. Plasma was not available. Fresh whole blood was called for but could not be quickly obtained. The patient was emergently evacuated from the forward surgical team to the combat support hospital but arrested in flight and could not be resuscitated. He was pronounced dead shortly after his 45 minute flight to the combat support hospital."

Unfortunately, almost every surgeon deployed in a combat zone has heard this story or another variation with the same outcome. Surgeons are driven to intervene with the knife, but in combat knowing when to not operate is a critical decision that requires sound judgment. Forward Surgical Teams and other similar units operate forward on the battlefield in austere conditions. They are designed to be light and mobile so they can maneuver with combat units and provide rapid life saving surgical intervention if needed. The mission of the FST is sometimes said to be life, limb, and eyesight salvage. A more succinct description is quite simply to stop the bleeding! Forward Surgical Teams are designed to stop hemorrhage and control contamination in the neck, chest, abdomen, retro-peritoneum and extremities. They can also stabilize fractures. They are equipped with little to no radiology or lab support with exception of a portable ultrasound and an I-Stat. The environment is often hostile and the conditions require rapid effective surgery and early safe evacuation. Key to effective treatment is the ability to rapidly transfuse blood products including fresh whole blood and plasma.

In Afghanistan and Iraq as the theater has matured, Forward Surgical Teams have been augmented with fresh frozen plasma, cryoprecipitate, fixed facilities, mechanical operating room tables, portable chest X-ray machines, and portable oxygen generators. Creative commanders have obtained other highly technical equipment. Unfortunately many of the teams have been split reducing the number of personnel from 20 to 10 which despite the advantage of more sophisticated equipment, significantly degrades their already limited capabilities. Although the capabilities are limited, FSTs have made a significant impact in the Global War on Terror by following a few basic tenets.

Advanced Trauma Life Support

Forward surgical elements are expertly trained to provide **combat-modified** ATLS. The basic tenets of ATLS are Airway, Breathing, Circulation, Disability, and Environment (ABCDE). The highlights of this process at the FST level are:

Airway. Put your anesthesia provider at the head of the bed to manage the airway, and facilitate transfer to the operating room. You should have a set pre-made at the bedside with the airway equipment and surgical airway tray. A #4 Shiley tracheostomy tube is ideal for cannulating the trachea.

Breathing. If the patient has a hole in the chest, put in a chest tube. If there is evidence of tension, do a needle thoracostomy and then put in a chest tube. Tube thoracostomy is an easy way to save a life and 70–90% of patients stop bleeding from their chest with this maneuver.

Circulation. Stop bleeding (pressure, tourniquet) and get IV access that is reliable and well-secured prior to transport.

Disability. Document the Glasgow Coma score. If less than 8, intubate the patient. See if the patient can move all extremities and check gross sensory function to touch.

Environment/expose. Expose entirely and look everywhere – small holes will elude the superficial exam. Make sure your unit has adequate heaters and WARM the room.

It is important that each member of the team understand their role during ATLS. The nurse anesthetist is responsible for evaluating and maintaining the airway. Two medics obtain IV access while a surgeon conducts the primary survey. One registered nurse records the resuscitation while another member of the team runs labs. A medic is ideally suited to run blood products through a rapid blood infuser while another may be responsible for obtaining needed instruments. How ATLS is coordinated and conducted depends on the commander, but be sure to have a well rehearsed plan.

Secondary Survey

The secondary survey in the austere environment remains focused on sources of bleeding. The sources of life-threatening bleeding are the chest, the abdomen, the retroperitoneum, the lower extremity compartments and blood lost in the field before effective control of hemorrhage is obtained. The holes will frequently guide you to the source of bleeding. Blood in the chest can be detected with chest X-ray if it is available or tube thoracostomy. If the chest tube puts out more than 1,000 cc then thoracotomy is warranted. Identify and document all injuries using the Joint Theater Trauma Record. Determine if the patient will require surgery and begin to plan for evacuation of the patient – even if they are going to the OR first. A typical initial evaluation of the combat trauma patient should be complete in 5–10 min. All life threatening injuries should be identified and if necessary resuscitation should have begun. Crystalloid infusion should be minimized. Patients in shock should be resuscitated with blood products.

Resuscitation

A 24-year-old male US Soldier was inbound to the Forward Surgical Team. He would arrive in approximately 20 min. He was reported to have a gunshot wound to the right chest and both lower extremities. His heart rate was 150 and his blood pressure was 100 systolic. The medic reported he was conscious but confused. No other information was available. A fresh whole blood drive was called for immediately and anticipating the need for plasma, thawing of 4 units of FFP was begun. Upon arrival the patient was somnolent with a blood pressure of 88 and a heart rate of 144. An entrance wound was present in the upper left chest and the abdomen was distended. A left tube thoracostomy was performed with return of about 100 cc of blood. An 8f left subclavian catheter was placed as well as two large bore IVs. The patient received immediately 4 units of packed red blood cells and 4 units FFP. No other life threatening injuries were identified and the patient was taken to the OR for exploratory laparotomy within 15 min of arrival.

Effective resuscitation of the patient begins with a good plan. Forward surgical teams doctrinally carry 20 units of PRBCs which are immediately available. Fresh frozen plasma is also sometimes available but it is stored at −20° centigrade and takes 30 min to thaw. Platelets can only be stored for 5 days and are not typically available far forward. Fresh whole blood is frequently used as a platelet substitute in combat and is an excellent resuscitation fluid as well, but it is drawn fresh from available donors and it takes about an hour to get the first unit. You must anticipate the need for these products. Develop a walking blood bank and rehearse implementing it a few times before you actually need it. Table 34.1 lists the components of an effective emergency fresh whole blood collection procedure. Figure 34.1 shows the required equipment and Fig. 34.2 shows a whole blood draw being performed. Type O blood is the only PRBC type available at the FST. O positive

Table 34.1 Emergency fresh whole blood collection procedure

1. Develop a roster of prescreened donors. In all cases, have the donor complete a DD Form 572-Blood Donation Record. Exclude high risk donors. Prior blood donors have been screened previously for transmittable disease. Donors with recent laboratory confirmation of blood type are ideal because identification tags are incorrect 2–11% of the time.
2. Clean the donor's arm with povidone-iodine of chlorhexidine solution for 1 min.
3. Draw the blood from an arm vein into a single donor blood collection bag containing anticoagulant such as citrate, phosphate, dextrose, adenine (CPDA) solution. Draw about 450 cc of blood until the bag is almost full.
4. Draw tubes of blood for typing and cross-matching (EDTA [ethylenediamine tetraacetic acid] purple top) and for testing of blood-borne infectious disease (two serum separator tubes, red and gray tops). The serum separator tubes should be centrifuged for 20 min prior to shipment.
5. Inform the operating room team (before transfusing blood) that emergency draw fresh whole blood is about to be transfused and confirm blood type and pertinent patient history.
6. Document clearly who the blood was donated from and to whom it was transfused.
7. Obtain and follow any additional theater guidelines and policies for the transfusion of fresh whole blood.

Equipment Required for Fresh Whole Blood Collection

1. Blood recipient set (collection bag), indirect Tx Y-type.
2. Stopcock, IV therapy three-way, with Luer.
3. Serum separator blood tubes.
4. EDTA tubes.
5. Centrifuge.

Fig. 34.1 Set for collection of warm fresh whole blood for combat transfusion and resuscitation

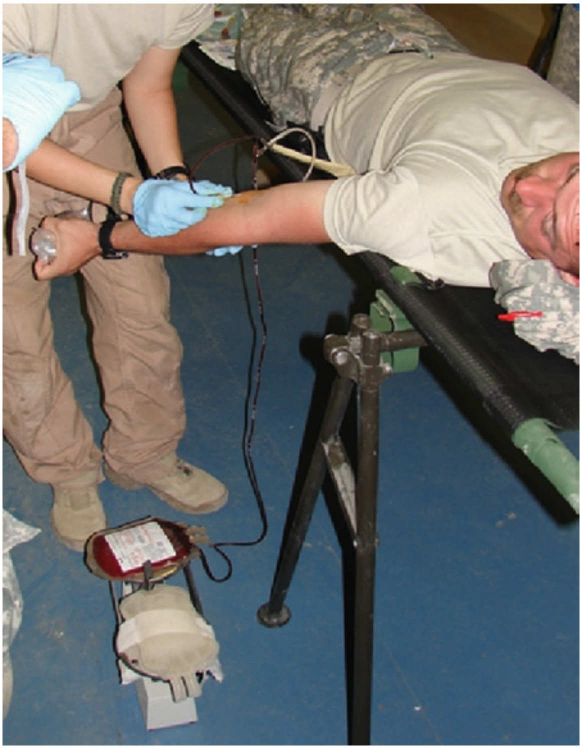

Fig. 34.2 Whole blood donation at a Forward Surgical Team

blood is generally used for male patients and type O negative is used in female patients. The universal donor for FFP is type AB. Type A FFP is generally considered a safe alternative to type AB when large amounts of plasma must be transfused.

Forward Surgical Intervention

The previously mentioned 24 YO male with the gunshot wound to the chest had received 4 units of PRBCs and 4 units of FFP. In the operating room the patient was sterilely prepped and draped before induction of anesthesia. The surgeons were gowned and prepared to open at induction. Predictably, the patient became profoundly hypotensive during the course of receiving anesthesia and the opening of the abdomen. All 4 quadrants of the abdomen were packed starting with the region of the liver which was a clear source of major hemorrhage. Packing the liver only slowed the bleeding and a Pringle maneuver was performed. The liver was mobilized and packed posteriorly which also failed to stop the bleeding but slowed it down. This allowed the ongoing transfusions of FFP, PRBCs and FWB to maintain the blood pressure. Eventually, the liver bleeding was controlled by ligating major vessel through the injured parenchyma. Injuries of the stomach, duodenum, small bowel and colon were controlled rapidly with a GI stapler and intestinal tract continuity was not re-established. The abdomen was irrigated and temporarily closed. During the operation the patient received 12 units of PRBCs, 13 units of FFP, and 12 units of FWB. His base deficit in recovery was −3.

The transition from the resuscitation of the combat wounded to surgical intervention must be well coordinated and seamless. In the most severely injured patients a period of profound hypotension must be anticipated when the patient receives initial anesthetic agents during intubation and when the surgery begins, especially when a tamponaded body cavity is initially entered. Reliable large bore IV access, infusion of all fluids through a Belmont or Level 1 rapid fluid infuser, warming all fluids to 40°C, maintaining the patient's body temperature, giving rFVIIa early, and assuring the availability of required blood products are key factors. Remember to give the patients antibiotics and a tetanus booster as well. In the cited example the team was able to keep up with the blood loss even though it was significant. It is difficult to anticipate which patients may require massive transfusion, but Fig. 34.3 is a reasonable algorithm for a far-forward team with limited blood supplies.

It is beyond the scope of this chapter to describe in detail all of the possible surgeries a FST may be required to perform, but there a few operations that if mastered will yield optimum results. Table 34.2 lists the life and limb saving operations that the FSTs were designed to perform. As an example of the typical mission, the 541st FST during a 15-month deployment in Afghanistan treated 761 trauma patients. 327 of these patients required surgery. The majority were injured by penetrating mechanisms, with over 40% coming from major explosive incidents. 108 patients had severe or

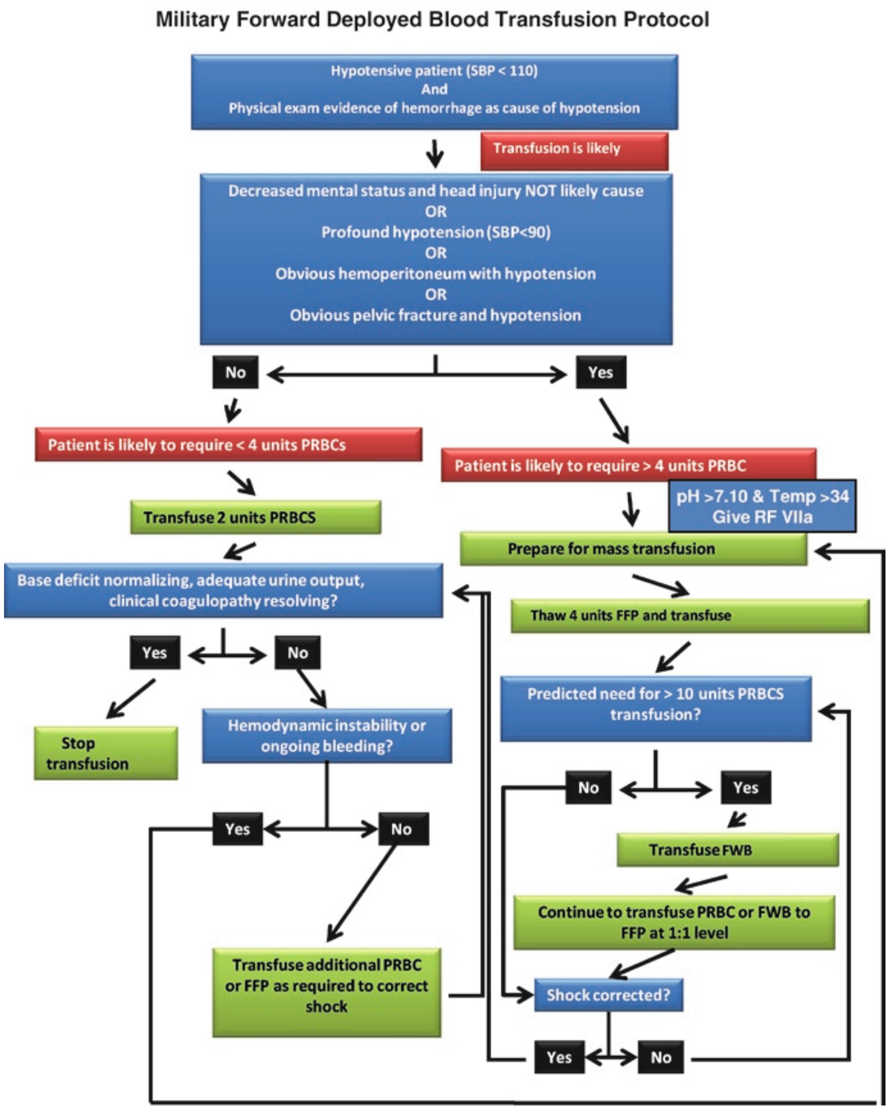

Fig. 34.3 Algorithm for massive transfusion in a far forward environment

very severe wounds by Injury Severity Score and the overall died of wounds (DOW) percentage was 2.4%. These are results that are as good as any trauma center, and that were achieved with minimal personnel in a harsh environment with limited supplies and equipment. This is what a focused and well-led team of professionals can accomplish.

Table 34.2 Examples of high yield surgical procedure for the far forward surgical element

ATLS
Tube thoracostomy
Cricothyroidotomy
Central line placement
Pelvic binder placement
Neck
Neck exploration
Chest
Anterior thoracotomy
Pericardiotomy
Tractotomy
Abdomen
Exploratory laparotomy
Splenectomy
Liver mobilization, packing, Pringle maneuver
Right and left visceral rotation
Resection of bowel
Nephrectomy
Suprapubic bladder catheterization
Abdominal packing
Temporary closures
Vascular
Exposure of vascular injuries
Shunt placement
Extremities
External fixation of long bone fractures
Fasciotomy
Escharotomy
Debridement and washout
Splinting
Amputation

Evacuation

Whether you are at a very small Forward Surgical Team or a more robust and larger Combat Support Hospital, you must realize and anticipate the situational "danger-zones" to avoid. Transport from one facility to another is one of the most vulnerable and dangerous times for a patient, and the sicker they are the more dangerous it becomes. This fact is often under-appreciated by physicians, who rarely are required to participate in these evacuation missions. Impress this danger upon your people, particularly the surgeons, and ensure you have a protocolized approach to the transfer process that anticipates in-flight disasters.

Forward Surgical Teams under the best of circumstances are not equipped to hold or manage wounded patients. Theater medical commanders must understand that holding patients at the FST will significantly impact the unit's ability to receive new patients. Evacuation of patients in the immediate post-operative period is critical to successful forward surgery. Almost all patients wounded in Iraq and Afghanistan are evacuated by MEDEVAC helicopter. The crews of these aircraft are remarkably professional and dedicated, but there are several pitfalls that must be avoided if patients are to be safely evacuated. The perfect damage control surgery can be undone by the simplest of problems during the transportation process, and anticipation is the key to prevention.

Airway Management during evacuation is extremely difficult for several reasons. Inadvertent extubation of paralyzed pharmacologically paralyzed patients has occurred. These events have resulted in fatalities in patients with survivable wounds. The configuration of the helicopter makes it difficult for the medical attendant to evaluate the patient's airway and the noise makes it nearly impossible to hear breath sounds. Add to this the technical difficulty of actually intubating a patient in flight with the relative inexperience of most flight medics and the problem becomes clear. A very good and safe practice is to extubate post-operative patients if at all possible prior to transport, followed by a short but adequate observation period to assure airway and breathing stability prior to transfer.

Size E oxygen cylinders are usually used to transfer patients. At a flow rate of 10 L/min a full tank will last about 60 min and at 6 L/min it will last about 2 h. It is not uncommon in flight to have to switch cylinders so make sure the personnel transporting the patient have the appropriate training. If you run out of oxygen because you didn't anticipate the flight taking longer than expected or the patient requiring more, then you (and your patient) are out of luck.

Hypothermia is a major risk to trauma patients during evacuation. The US ARMY has developed a Hypothermia Prevention and Management Kit (HPMK) to prevent this serious complication. Figure 34.4 shows a patient in a HPMK. Place all patients in one these kits, even in the summer in the desert. Hypothermia happens with injured patients even in 105° heat, particularly on helicopter flights.

Fig. 34.4 Packaging of a patient in the Hypothermia Prevention and Management Kit (HPMK) prior to transfer from a forward surgical unit

Occasionally patients are so critically injured a member of the team may need to attend the patient during evacuation. The small nature of the teams and the relative importance of the surgeons and nurse anesthetist make them a poor choice to accompany these patients on MEDEVAC missions. In split based operations the loss of these personnel will make the team mission incapable until they return. A reasonable approach is to select one or two of the registered nurse to attend the flight nurses course and then use them on the occasions a medical attendant is required. However, very unstable or high-risk patients may require a provider-level escort, and the anesthesia personnel are usually the best prepared for this job (Fig. 34.5). Alternatively, reassess whether you need to transfer the patient immediately or whether a short delay might improve the situation. Unlike civilian practice, you may be transporting patients directly from an operating room table to a waiting helicopter for transfer.

Major limiting factors for patient care on these flights are the cramped quarters, limited access to the patient, and poor illumination and visibility (Fig. 34.6). For security reasons these missions often occur at night, which is good for the pilot and crew but bad for you and the patient. You will not be allowed to use standard white light, and will have to rely on (and remember to bring) a filtered light source (green or red usually). It is extremely dangerous to MEDEVAC patients on low illumination nights. These high risk missions should only be flown if absolutely necessary. Adverse weather conditions can also adversely impact the ability to evacuate patients.

Fig. 34.5 Certified nurse anesthetist (CRNA) prepares for helicopter transport of a critically ill patient with critical supplies and medications readily available from his vest and the pre-stocked flight medicine bag

Fig. 34.6 CRNA prepares two critically ill patients for transport in the cramped quarters of a Blackhawk medical evacuation helicopter

Do not put flight crews at risk unnecessarily. If you can wait till morning or until the weather clear to evacuate patients, do so.

To succeed at transporting severely injured patients in a combat environment, training and preparation are your friends. Identify your personnel who will serve as flight medics and have them all complete a flight medicine training course. If protocols for the evacuation process are not in place, then develop them. This should include standardized order sets to prepare the patient for evacuation (Fig. 34.7) and for in-flight treatments (Fig. 34.8). Have pre-made flight bags with critical medicines and supplies placed in standard locations (Table 34.3) so the flight medic can just grab and go. The final and most important aspect is recording all in-flight data and any adverse events so that you can continuously monitor and improve the process.

The transfer of medical records and critical information continues to be a significant problem in current combat operations. Do not count on having internet access or even functioning computers and printers in far forward settings, particularly in the early phases of combat operations. Even telephone or radio contact with the receiving facility may be limited or unavailable. Handwritten records are used, but are frequently damaged or altogether lost during transport. One of the most low-tech but effective back-up methods for ensuring critical information is relayed is by keeping it on the body of the patient. Write the critical information on the patient dressings with permanent marker and in large, clear print (Fig. 34.9). This will facilitate the patients subsequent care and be greatly appreciated by the receiving physicians.

MEDEVAC PRE-FLIGHT CHECKLIST

Once the decision is made to transfer a patient, and an accepting physician has been obtained, the following steps will be taken to prepare the patient for transport:

Initials	Evaluation steps
	1. Sending physician identified: (Printed name)______________________ Flight nurse identified and called to unit: (Printed name)______________________
	2. Anesthesia called to unit for intubation if indicated. **ETT secured**.
	Preparation steps
	Positioning and Proper Monitoring, Initiating Nine Line
	1. Patient moved to litter (collapsible handles), positioned, padded, strapped, equipment (with necessary attachments) added and secured.
	2. For head-injured patients, a presedation neurologic examination will be performed. This assessment will be documented on the enroute care form, and a copy of this form will remain at Balad with the patient.
	3. Ventilator set with standard settings (switched to Impact vent) or as directed by intensivist.
	4. IV access verified, secured, and made readily accessible.
	5. Arterial line inserted and secured if applicable. Transducer accessible.
	6. Ventilator tubing checked to be free from obstruction and secondary lines attached.
	7. Unless contraindicated, an orogastric or nasogastric tube is inserted, placement verified with chest x-ray, and attached to low-intermittent suction until the time of departure from the CSH.
	8. Chest tubes to water seal (if applicable).
	9. Nine lin e called at _______________ by the Flig ht Nurse.
	Equipment, medication, chart, and personnel preparation:
	10. Medications needed for flight prepared and organized (See Medevac Standard Orders): ____Sedation ____Analgesia ____Vasoactive ____Fluids ____ACLS Meds ____Paralytics ____Neuro agents
	11. Flight equipment bag obtained and checked. Backup pulse oximeter readily available.
	12. Complete chart photocopied (including xray cd), patient belongings (including medals) assembled
	13. Ear plugs for patient and flight nurse
	14. RN verifies Uniform, Kevlar, IBA with DAPS, Weapon, ID Card, and CSH contact information. Bring bag to carry equipment on return trip if possible.
	Ventilator management
	15. 15 minutes after initial ventilator settings, blood gas (preferably abg) obtained. All efforts will be made to have a documented blood gas (preferably abg) within 30 minutes of flight time.
	16. Respiratory therapy to unit to adjust ventilator settings: RT name_______________ R.T. to check that O2 tank appropriate for length of flight. PSI:__________, Ambu bag under patient's head with tubing connected to O2 source, vent tubing free from obstruction
	Final verification:
	17. Physician, Medevac nurse, and Respiratory Therapist to verbally agree on the plan of action
	18. Medevac order sheet reviewed and signed by Medevac physician. Any additional orders will be explicitly stated on this same order sheet.
	19. En route care form available with preflight data completed.
	20. Re-evaluate equipment function and troubleshoot as necessary until flight arrival.
	21. Immediate pre-departure assessment by Medevac nurse and physician. Document on en route care form.
	22. 99 advised of transfer and will advise the TOC

Fig. 34.7 Standardized set of pre-flight orders to prepare a patient for evacuation

Command

The commander of the forward surgical team is usually a surgeon. It is important for general surgeons to take on this responsibility. Surgeons are uniquely equipped to train and deploy teams whose specific mission is surgery. The priority of the surgeon commander will necessarily be providing the very best trauma management possible but there are many other components of command that are very important. Table 34.4 lists the FST critical commander's intelligence requirements (CCIR).

Take care of your people. Take the time to train them well and then reward them by diligently working on their evaluations and awards. Awards and evaluations are important in the military and you should try very hard to advance your

MEDICAL RECORD - PROVIDER ORDERS
For use of this form, see MEDCOM Circular 40-5

DIRECTIONS: The provider will DATE, TIME, and SIGN each order or set of orders recorded. Only one order is allower per line. Orders completed during the shift in which they are written will be signed off adjacent to the order and do not require recopying on other ITR forms.

DATE/ TIME	ORDERS (SIGNATURE REQUIRED FOR EACH ORDER/SET OF ORDERS. SIGNATURE MUST BE LEGIBLE; PROVIDER WILL USE SIGNATURE STAMP OR PRINT NAME).
	MEDEVAC STANDARD ORDER SET **Planned Flight to**___________________
	Diagnosis:_______________________________________ **Sending Attending Physician:**___________________
	Vitals: [ ]Q5 min [ ]Q10 min
	Nursing: [ ] Wound Vac dressing to 150 mmHg suction
	[ ] NGT to Suction/Clamp NGT
	[ ] Chest tube to Water seal/20cm H20 suction
	IV Fluids: [ ] LR______cc/hr [ ] NS_____cc/hr [ ] 3% Saline_____cc/hr
	Sedation and Analgesics:
	[ ] Versed 1-5mg Q 10 minutes IVP PRN sedation to Ryker of 1-2 (see reverse)
	[ ] Haldol 5-20mg Q20 minutes IVP PRN sedation to Ryker 1-2
	[ ] Ativan1-6mg Q20 minutes IVP PRN sedation to Ryker 1-2
	[ ] Fentanyl 25-200mcg Q10 minutes IVP PRN pain
	[ ] Morphine 1-10mg Q20 minutes IVP PRN pain
	Paralytics: [ ] Vecuronium _____ mg IVP for paralysis for patient safety en-route
	Intracranial Hypertension: [ ] 3% Hypertonic Saline 250ml bolus for any signs of herniation
	Vasoactive Drugs:
	[ ] Neosynephrine gtt at _____mcg/min, titrate to MAP >_____
	[ ] Neosynephrine 40-300mcg IVP Q5 minutes for MAP < _____
	[ ] Dopamine gtt at_____mcg/kg/min, titrate to MAP >_____
	[ ] Dobutamine gtt at_____mcg/kg/min, titrate to MAP >_____
	[ ] Levophed gtt at_____mcg/min, titrate to MAP >_____
	[ ] Vasopressin 2.4 units/hr
	[ ] Other____
	Labs: [ ] ABG 15 minutes prior to leaving 28th CSH [ ] ABG on arrival at receiving theater hospital
	Respiratory: [ ] O2 via NC or Face Mask to keep sats > 95%
	[ ] Vent settings: MODE: SIMV/AC; RATE:_____bpm; TV:______; PEEP:_____; PS:_____ ; FiO2 _____%
	[ ] TXP Ventilator: RATE:_____bpm ; PEEP:_____; PIP:_____

PATIENT IDENTIFICATION *(For typed or written entries note: Name - last, first, middle initial; grade; DOB; hospital or medical facility)*

Complete the following information on page 1 of provided orders only. Note any changes on subsequent pages.

Diagnosis: ____

Height: ________ **Weight (lbs):** _________ **Diet:** ________________

Allergies: ____

Nursing Unit	Room NO.	Bed No.	Page No.

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Fig. 34.8 Standardized orders to direct in-flight care during medical evacuation missions

best people. On the other hand, you must have the personal courage to remove people from your team who can't do the job. The FST can't carry anyone who is not up to speed.

Develop a comprehensive training plan before deployment. Operate with your own people in your operating room whenever you can. Arrange to have your medics

Table 34.3 Flight bag packing list

Right side pocket
1″ Silk tape – 1 roll
2 Tourniquets
Alcohol pads – 5
1 Carpuject
16′ IV cath-2
18′ IV cath-2
20′ IV cath-2
Left side pocket
Pressure bag
Gravity tubing
500 ml Hextend
Front right pocket
1″ Silk tape
1 Roll kerlix
2×2 Gauze-4
1 Roll coban
2 Pair latex gloves
4×4 Gauze – 4
Front left pocket
2 portable SPO2 probes
Oxygen wrench
Trauma shears
Middle right pocket
18′ Needles – 10
Filter needles – 2
10 ml Syringes – 5
10 ml Pre-filled saline flush – 4
Zofran 8 mg
Middle left pocket-medications
100 ml NS with 10 mg Neosynephrine
20 mg Lidocaine – 2
1 mg Atropine – 3
13.6 mEq CaCl – 2
1 mg Epinephrine – 3
Lid pouch
Scalpels – 2
Suction catheter 16 Fr – 2
Tongue depressor – 2
Nasal airway – 2
Oral airway – 1
NRB – 1
Back main pocket
Suction tubing with Yankaur – 1
Ambu bag mask
Toomey syringe
E-Z Cap ETCO2 device
3% Saline (as needed)
40 µ Vasopressin
10 ml Saline vial – 2
10 ml Sterile water – 2
10 mg Vecuronium – 2

Fig. 34.9 Critical details of the damage control surgery and resuscitation are written in clear permanent ink directly on the patient's dressings

Table 34.4 Suggested FST critical commander's intelligence requirements

1. MEDEVAC availability.
2. MEDEVAC range and flight times.
3. MEDEVAC flight time from forward location to supporting combat support hospital.
4. Available blood products and expiration dates.
5. Medical equipment availability and readiness status.
6. Medical supply shortages.
7. General knowledge of ongoing tactical operations.

and nurses work shifts in the hospital and then bring your team together by attending the Army Trauma Training Center or a similar training exercise. Teach your team how to conduct ATLS, resuscitation, and advanced current trauma tenets before deployment. Make the training realistic, but do not allow anyone to waste you teams time with unproductive training before deployment. Your team will need time with their families and friends.

Manage your property well and arrange movement of you equipment to theater early. Know the chain of command in theater and interact with the forward operating base commanders. Demonstrate confidence in your team so they know their soldiers will be well cared for, and let them watch you work. They will be very appreciative of your efforts.

Have and rehearse an effective MASCAL plan. It is not uncommon to get several patients at once in combat. When this occurs, small teams can be quickly overwhelmed. Overtriage is a phenomenon where many of the patients brought to a hospital are not badly injured. This is compounded in combat due to the need to quickly clear the battlefield. Key to any MASCAL plan is an effective triage plan that allows identification of patients who truly need ATLS. This plan should be coordinated at the forward operating base level and should include locations for patient overflow, non-medical personnel for patient transport and FWB donation and tactical personnel for security as well as available combat life savers and medics.

Conclusion

Care of the combat wounded in the far forward setting can be a daunting task. Expert ATLS, early use of packed red blood cells, fresh frozen plasma, and fresh whole blood, and appropriate timely resuscitative surgery will save lives. Plan for safe early evacuation and even your most severely injured patients will do well. Seek command and responsibility and always remember what a unique opportunity it is to serve our soldiers and a great nation at war.

Chapter 35
Humanitarian and Local National Care

James Sebesta

Deployment Experience:

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General Surgeon, 8th Forward Surgical Team, FOB Shank, Afghanistan, 2009

BLUF Box (Bottom Line Up Front)

1. There is no faster or more effective way to "win the hearts and minds" of the local citizens than by providing quality and compassionate medical care to them and their loved ones.
2. Humanitarian and local national care must always be done within the framework of the medical rules of engagement (MROE), but you can often adapt this framework significantly to your particular situation.
3. Local populations with little access to modern medical care will seek out US medical units, so it often takes little to no outreach to establish these programs.
4. Every US medical unit should have a person who is responsible for coordinating transfers of local nationals into the local hospital or outpatient care system. This should usually be a local national with medical experience and contacts.
5. Operating a local national clinic can benefit both the patients and your unit by keeping their medical and surgical skills sharp.
6. Provide as much as you can, but do not ever compromise your primary mission of caring for combat casualties.
7. You may need to supplement your unit supply list to provide more elective type surgical care, particularly for pediatric patients.
8. Participating in education and training programs is one of the greatest gifts you can make toward the future of the local populace.

Never underestimate the power of a small but committed group of people to change the world. Indeed, it is the only thing that ever has.

Margaret Mead

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Deployments can provide a surgeon with a wide range of experiences. Depending on your location, patient flow may make you feel like you are drinking from a fire hose or it can be totally absent and your time is spent surfing the internet and working out. Some areas may experience occasional surges in patient numbers separated by long periods of inactivity due to the operational tempo (OPTEMP) of the units around you. Local national patient care is one way to improve your operative experience while keeping your team busy and their skills polished. Surgical care for local nationals has the added benefit of helping to "win the hearts and minds" of the local population. There is no better tool for instantly winning the friendship and admiration of the local community than by taking care of their sick or injured loved ones. This can be an effective tool for improving intelligence and creating an environment that is increasingly friendly to USA and Coalition forces (Fig. 35.1).

Humanitarian aid or local national care can come in many forms including; Medical Rules of Engagement (MROE) positive patients, Medical Civic Assistance Programs, Local National treatment clinics and educational opportunities for local national physicians and nurses. The amount of planning and prior coordination will depend on the type of care that you are providing. Your ability to provide the various levels of care will also depend on the type of medical unit you are located with and

Fig. 35.1 Iraqi government and civilian officials presenting gifts of thanks for the care delivered to injured local policemen at the 47th Combat Support Hospital in Tikrit, Iraq. Inset: Afghani citizen presents a token of appreciation to Forward Surgical Team member COL Craig Shriver

the amount of equipment and supplies available to you. The mission to care for United States and coalition forces personnel always takes precedent, and you must ensure that any humanitarian efforts that you undertake do not interfere with this. The best way to get buy-in and support from your superiors for engaging in humanitarian medical and surgical care is by open communication. Demonstrate how it can actually improve your unit's ability to accomplish the mission and overall morale and you will usually see resistance vanish and more personnel wanting to participate.

Medical Rules of Engagement Qualified

Medical rules of engagement are criteria established by the Task Force that is responsible for the regional medical care. Strict guidelines are established for the various types of injuries that can be treated in addition to the amount and type of care that can be provided. MROE positive injuries usually are limited to injuries that threaten life, limb or eyesight. Patients that are injured by Coalition activities are usually MROE positive but this can vary depending on the circumstances. In some instances, MROE dictates the type of treatment that can be performed. One example of this is the guideline that local nationals with greater than 50% total body surface area burns are only entitled to comfort care at US facilities. This guideline is based on the resource intensive nature of burns of this size and the absence of burn care or rehabilitation facilities in the host country that make these injuries nearly uniformly fatal. Another key consideration for whether a local national patient can be accepted and cared for is the hospital capacity and census. These rules usually dictate the refusal or diversion of local national patients when the census reaches 80 or 90% of capacity, leaving the remaining capacity for USA or coalition personnel in need of urgent care.

Qualifying for treatment at one facility based on MROE does not guarantee that additional care will be provided at higher echelons of care. This also doesn't guarantee follow-up care for that patient. This situation can create a disposition nightmare for smaller medical units. In some cases, your team will provide medical treatment to a patient for life threatening injuries for which the patient will need continued hospital care but the next higher echelon refuses to accept the patient due to limited bed space. This requires creativity and prior coordination with medical treatment facilities of all types. Small local facilities will sometimes take these patients if the family demonstrates the ability to pay for their care. Military or police hospitals in the host nation can be utilized if the family has any connection with these organizations. Other humanitarian aid organizations can provide short term care for some patients. In addition, the unit that injured or authorized transportation of the patient to your facility is responsible for arranging transportation back to the patient's home and assisting with disposition. In some cases, these patients may need to be held at your location until they are ready for discharge to home.

It is CRITICAL that you establish good lines of communication and policies with local hospitals or other medical facilities to facilitate the transfer or medical follow-up of local nationals that you have cared for. Before you do an operation or procedure that depends on close follow-up or postoperative therapies, you must ensure that either your unit can provide this or it is available in the local community. Do not assume that even basic things such as physical or occupational therapy, enterostomal therapy and supplies, limb prosthetics, or local wound care will be available to your patient once they are released from your care. In addition, because there is no medical evacuation chain for injured or ill local nationals it is critical that you have a mechanism in place to disposition them. If you do not, then your facility will quickly become mission incapable or compromised because of the bed-space and resources utilized by these patients. This was a very rapidly learned lesson in the early war experience that led to the hiring of local national medical liaison personnel at most facilities. Your medical liaison will be one of your most valuable assets in helping you navigate the often chaotic and byzantine local health care system for patient transfers or follow-up care.

Medical Civic Assistance Programs

Periodically, units will approach your team for assistance in a Medical Civic Assistance Program (MEDCAP) mission. These missions are designed to provide medical assistance to small towns or remote areas that lack any treatment providers. This is another method used by various units to “win the hearts and minds” of local people to improve the environment for USA and Coalition forces. MEDCAP missions require medics, nurses and physicians to perform quick symptom-guided examinations of patients and then provide medications to help improve their symptoms (Fig. 35.2). In this setting, time constraints and the lack of testing equipment require that presumptive diagnoses be made based on the history and brief physical examinations. Often patients are treated to relieve the symptoms despite the lack of a known diagnosis. A significant number of patients will present with common medical problems making their treatment fairly straight forward (Table 35.1). Patients with more complex disease processes such as cirrhosis, renal insufficiency, heart failure, diabetes should not be given more advanced treatments because of the inability to monitor their response to the treatment and for possible side effects. If a patient has a bad outcome from a treatment or dies, this can be twisted into the idea that the medical team poisoned the patient or is providing poor quality care.

MEDCAP medications are typically provided by the unit requesting the assistance with the mission. These units have funds that can be used to purchase medications from local vendors. Most of the medications are what we consider “over the counter” but are unavailable to the people in these regions. These units will need your assistance deciding on which medications and in what form. When ordering medications, remember that there will be men, women and children of all ages so having pill and liquid forms of the medications is important (Table 35.2). Additional items can include tooth brushes, tooth paste, soaps, clothing and recreational or sports equipment. You will be amazed at how far some soccer balls and equipment can go toward fostering good will in almost any part of the world.

Fig. 35.2 The 102nd Forward Surgical Team performing a MEDCAP mission in Kandahar, Afghanistan. Insets: Team members perform patient interviews via an interpreter (*upper left*) and focused physical exams (*upper right*) on local civilians

Table 35.1 Common medical problems encountered during MEDCAP missions

Headaches	Arthritis
Gastroesophageal reflux	Peptic ulcer disease
Parasitic infections	Urinary tract infections
Colds/Flu/Otitis media	Osteomyelitis
Malignancies (Breast, Skin, Oral)	Dental infections
Diarrheal diseases	Gynecologic

Table 35.2 MEDCAP medications

Tylenol	Motrin
H2 Blockers/PPI	Hydrocortisone cream
Multivitamins/prenatal vitamins	Mebendazole
Antibiotics	Peridex oral rinse
Antifungal cream	Antimalarials

To ensure that the unit setting this mission up gets the greatest return for its efforts, make sure to provide all of the services possible during that time. Coordinating with Veterinarian Services to de-worm and immunize local live stock can improve herd qualities and reduce disease related losses. Utilizing the services of the dentist to remove decayed and infected teeth will help to prevent long term complications and dramatically improve the patient's quality of life. Familiarizing yourself with the common diseases and infections of the indigenous population will save time and allow you to better tailor your medication and supply list. Physicians with training in Infectious Disease or Tropical Medicine are invaluable assets for these types of missions. To be effective, you must be able to communicate clearly and quickly with your patients. Ensure you have an adequate number of translators available, and if possible have translators with a medical background (local nurses or physicians).

There are a few things that are important to ensure a safe and successful MEDCAP mission. The first thing is to allow the line unit to provide transportation, security and the supplies to complete the mission. This is what they do and we need to use their expertise in these areas. Secondly, allow them to determine the location of the MEDCAP site. They are much more in tune with the communities that would benefit the most from the mission and the threat level associated with each area. When setting up at the site, try to be located inside a building or a perimeter wall to reduce your vulnerability to sniper or indirect fire. Patients should pass through security screenings more than once. Utilizing an outer perimeter with local national police or army forces that perform an initial screen followed by a secondary screening prior to entering the building will help prevent weapons or explosives from reaching the treatment area.

As physicians, we are often uninformed or unaware of the major security issues that even a simple convoy movement can entail. Despite your good will, medical units and personnel are very attractive targets for enemy attacks, often by indirect fire or suicide bombings. Efforts to improve relations with the local population will be looked upon as a direct threat to enemy and/or terrorist elements, and they will go to great lengths to destroy or discredit these missions. Do not advertise the date, time or location of the mission. Doing so will significantly increase your chances of IEDs or organized attacks. You should plan on one interpreter at each of the screening points and for each of the providers. The interpreters assist you with all parts of your interaction and provide verbal and written instructions on medication use. Without this amount of support, your ability to see large numbers of patients will be severely hampered

Local National Clinics

Some of the most rewarding experiences from deployments can come from developing a clinic that provides care to the local national population. These clinics provide an opportunity to provide care that is either not available or is not safe in the local community. It also exposes surgeons to disease processes that may not be seen in their normal practices. These include; rabies, cutaneous tuberculosis, giant inguinal hernias with loss of domain, enormous goiters, echinococcal disease and very advanced forms of tumors or malignancies (Fig. 35.3). It also has the added benefit of providing you a steady stream of surgical cases. In many cases you may be exposed to pathology or to levels of advanced disease that you just don't see in the typical civilian practice (Figs. 35.4 and 35.5).

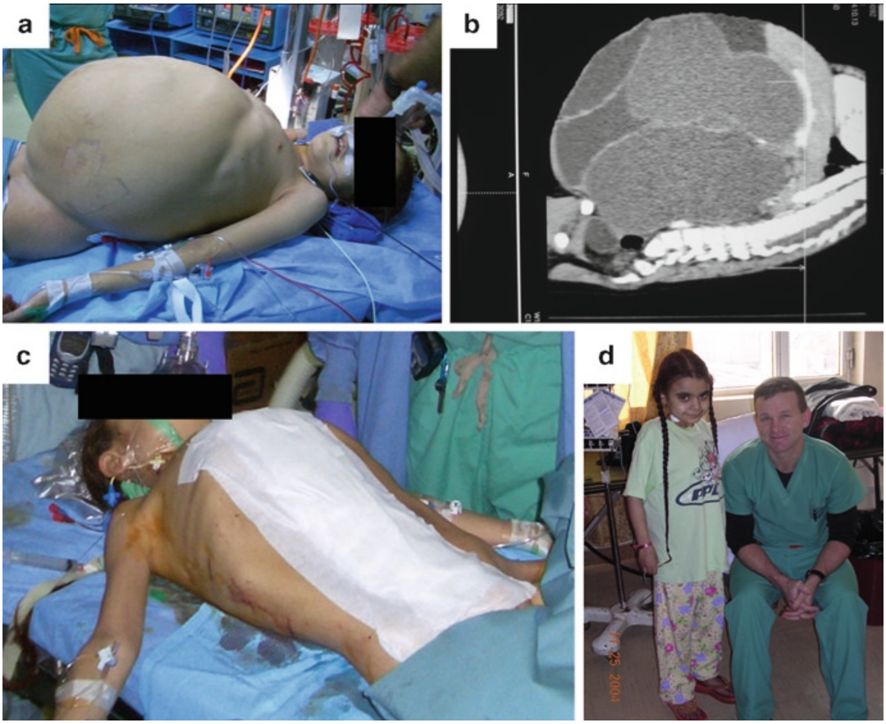

Fig. 35.3 (**a**) Young Iraqi female with massively distended abdomen; (**b**) Giant cystic abdominal mass on CT scan; (**c**) Same patient following laparotomy and mass resection; (**d**) Posing with her surgeon, LTC Tommy Brown, on the inpatient ward after surgery

The most effective local national clinics are operated in cooperation with a local physician. This allows the local physician to refer patients for care that they are unable to provide but more importantly, it gives the deployed surgeon the opportunity to educate and expand the capabilities of that local physician. This also helps to prevent your efforts from undermining the role of the local physician. In some areas, medical students and surgical residents can volunteer to be interpreters in exchange for the chance to work with deployed surgeons. This group also can provide an additional source of patients as they bring patients from their communities.

Local national clinics can be as large or as small as you would like to have. A balance needs to be achieved between the workload of the local national clinic, treatment of trauma patients and maintaining adequate time for you team to rest and perform their normal duties. In general, once you open your doors, word will spread like wildfire and the patients will begin to line up. It is important to firmly establish the numbers and the types of problems you will treat. Families will travel hundreds of miles to see a Coalition physician because they are told of the "miracle" treatments that can be provided. Patients with devastating strokes, spinal cord injuries, coronary artery disease and transplant desires will come to your clinic expecting treatment and even cure. Establishing guidelines will help to decrease these kinds of problems.

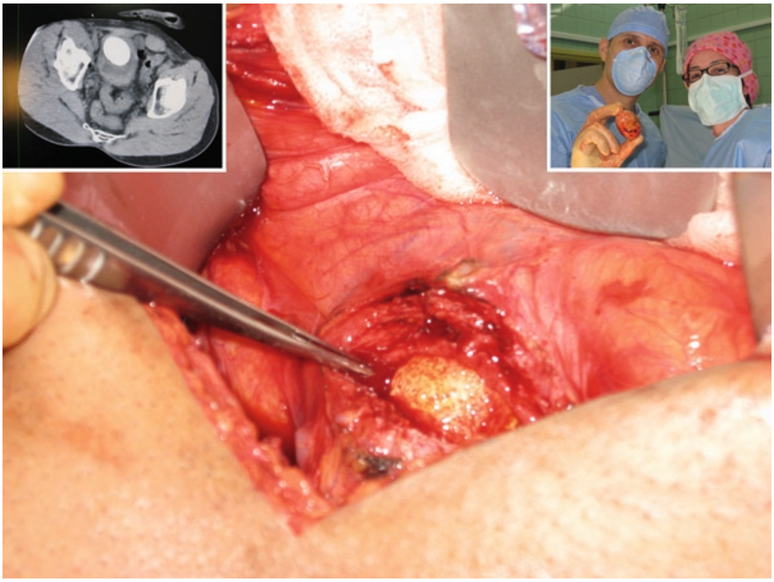

Fig. 35.4 Giant bladder stone being removed via cystotomy in an Iraqi civilian patient seen in the 28th Combat Support Hospital clinic. Insets: CT scan shows the large bladder stone (*left*) and the stone displayed by the operating surgeons (*right*)

Fig. 35.5 Four year-old Iraqi female with giant lymphangioma of the tongue (inset) and immediately after (main figure) subtotal glossectomy done by general surgeons at a Combat Support Hospital

A good rule of thumb when establishing the kinds of treatments you will provide is that your patient should not need any further hospital care, rehabilitation or medications. Larger Combat Support Hospitals can tend to be more aggressive in their patient selection, but smaller units need to be very careful. Even if you can provide the necessary medication or treatment while you are there, there is no guarantee that the unit following will be willing or able to provide it. Most patients do not have the access to or the ability to pay for medications or additional treatments.

One of the keys to a successful local national clinic is determining the disposition of the patient prior to the procedure. For minor procedures, this is not much of an issue but for the major cases, having a preset plan that the family and the patient are aware of will help to prevent disposition nightmares. This is greatly simplified if a local physician is involved in the care. After surgery, the local physician can take the patient back to his facility for recovery and return the patient for any follow-up treatments. Families can arrange with the local hospital to provide hospital care or the family can take the patient home. With good cooperation between the local hospital, families, and coalition treatment facilities, even 30–40% TBSA burns can be treated as outpatients with good outcomes (Fig. 35.6).

Another consideration of local national care is the amount of resources required to treat each patient. This includes blood, dressing supplies and staff/facility time. In small units such as Forward Surgical Teams (FST), preplanning to ensure that the required supplies are on hand can facilitate the ability to perform surgeries. Prosthetic mesh, anoscopes/proctoscopes, and cement to make antibiotic beads are some examples of equipment or supplies that may not be standard for FSTs. Small units that lack adequate personnel to have rotating work shifts need to be very careful about doing surgeries that require a prolonged hospitalization. The patient that requires “around the clock” care can exhaust personnel and make your team less effective when battle injured patients arrive. Combat Support Hospitals will have a more robust supply system and staffing allowing for more complicated procedures to be performed (Table 35.3). Having adequate staffing and supplies is a particularly challenging issue in caring for local national children. The specialized equipment, and supplies for pediatric patients are often inadequate or absent, and the majority of deployed providers are less familiar with pediatric specialty care. Virtually every deployed unit will be involved with caring for sick or injured children

Fig. 35.6 Iraqi child with fractures and severe right leg burn underwent split thickness skin grafting at a Combat Support Hospital (*left*) and made an excellent recovery after inpatient and outpatient rehabilitation (*right*)

Table 35.3 Types of procedures

Forward surgical team	Combat support hospital
Hernias	Intra-abdominal malignancies
Skin and soft tissue tumors	Cholecystectomy
Anorectal diseases	Oromaxillofacial procedures
Osteomyelitis	Thyroid goiter
Contractures secondary to Burns	Appendectomy
Fracture splinting and fixation	Splenectomy
	Caesarian section

Fig. 35.7 (**a**) Army ICU nurse caring for a burned infant; (**b**) Premature baby delivered via emergent caesarian section; (**c**) Pediatric ICU care at a forward hospital; (**d**) CDR Carlos Brown and LCDR David Junker with Iraqi children sheltered at a Navy medical facility after a bombing incident

and you must anticipate this in order to succeed. Despite these limitations, deployed medical units have consistently gone above and beyond to provide an incredible array of care and services to these patients; from caring for premature babies or performing emergent caesarian sections to caring for adolescents wounded in combat (Fig. 35.7).

Performing surgery on the local national population requires a very thorough evaluation by the surgeon. Patients often will not know their age and may have never seen a physician prior to your visit. Simple things that rarely are problems in your practices can play a significant role when deployed. Nutritional factors ranging from malnutrition to vitamin and mineral deficiencies can be seen. Patients may not be able to keep their dressings or wounds clean and dry. Patients may not have access to dressing materials or medications or more importantly understand instructions about medications or wound care. Communicating through an interpreter may make getting an accurate review of systems nearly impossible. This can inhibit your ability to accurately assess the patient. Cultural differences may have the patient acting in ways that can result in complications. Examples include remaining NPO for days after surgery or remaining in bed for over a week after a minor procedure. Thorough counseling in addition to written instructions can help to reduce some of these challenges.

Educational Opportunities

The final area of opportunity is in providing educational opportunities for local care providers. This can take many different forms ranging from lectures to hands on patient care. Depending on the team's location, host nation care providers may include nurses, mid-wives, medical students, residents and practicing physicians. Utilizing the nursing and physician expertise from your unit can provide the material to perform a wide range of educational activities in regions where continuing medical education is unavailable. These educational opportunities are best performed within the safety of your compound but in some cases, these will be done at the local hospitals or other facilities. These classes may be given in the lecture form with an interpreter or hands on class such as basic trauma life support classes using a live tissue model. Depending on the incidence of a particular disease, hands on patient care can be the format to teach care providers various stages of treatment. The treatment of burns and basic wound care are good examples of this form of teaching.

In any combat zone or country affected by war and other internal conflicts, the local medical system is often decimated and needs to be rebuilt from the ground up. Iraq serves as an excellent example of this, where much of the infrastructure was destroyed or looted, and the medical profession suffered a severe "brain drain" with medical leaders and physicians fleeing the country. Helping to support and rebuild these crippled systems then becomes one of the primary missions of deployed medical forces, and this starts with education of a new generation of medical providers. The initial education efforts should focus on training local nurses and physicians to care for the common and more emergent conditions that they will be facing, such as traumatic injury. A good example of this type of program is the Iraqi Trauma Training Program which was established by US forces at the Ibn Sina Hospital in Baghdad, Iraq. With a relatively small investment, a training center was established that provided local physicians and nurses with a multi-week course modeled after basic medic and EMT training, as well as the ATLS course. The course was continuously staffed by a series of rotating nurses and physicians assigned to the medical unit operating the hospital. Graduates of this program are then able to put their newly acquired knowledge and skills to work in their local hospitals and clinics, and to conduct training of other health care providers.

These educational opportunities provide updated information to care providers who have had almost no contact with current methods. It also provides a platform that allows you to develop friendships and working relationships with the local treatment facilities. Physicians are generally very highly respected in their communities and these friendships can be an important step in building alliances between coalition forces and community leaders. It can also expose deployed care providers to experiences that are rewarding and rarely available to them in their current practice.

Final Points

Deployment to a combat zone will be one of the most memorable periods of your professional career, for both positive and negative reasons. One of the best ways to help ensure that something positive comes out of the incredible destruction and misery of war is by actively participating in the humanitarian opportunities available to you. If none are available, then you have a great opportunity to establish such a program and truly make a difference for your patients, your colleagues and unit, and yourself. You may want to dull your memories of wartime medical care, but these are the experiences and the patients that you will never forget (Fig. 35.8).

Fig. 35.8 Military physicians and nurses with their memorable local national patients

Chapter 36
Expectant and End of Life Care in a Combat Zone

Robert M. Rush, Jr. and Matthew Martin

Deployment Experience:

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BLUF Box (Bottom Line Up Front)

1. There is no faster cure for the “God complex” than serving in an austere medical environment.
2. You will not have unlimited resources or transfer options available, and will have to make some hard life and death decisions.
3. Severe head injuries and major burns (>50% body surface area) will be your two most common reasons for providing expectant care.
4. “Expectant” care does not mean “no” care. Don’t ignore or forget them.
5. Set aside a separate area for expectant care, with privacy but adequate access to health care providers.
6. Comfort, compassion and dignity should be the cornerstones of expectant care.
7. Remember to take care of your personnel also. Expectant care exacts a heavy emotional toll – **particularly on the nursing staff**.

(continued)

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BLUF Box (Bottom Line Up Front) (continued)

8. Having a "group huddle" and discussion after a particularly difficult case can work wonders for individuals and the team.
9. If you have a scarce resource that could save multiple lives, do not waste it on a heroic but low probability attempt to save one life.

Above all, let us remember that our duty to our patients ends only with their death, and that in the preceding hours there is much that we can do for their comfort. At the very least, we can stand by them.

Alfred Worcester, 1855–1951

A severely wounded soldier arrives by helicopter at your Combat Support Hospital or Forward Surgical Team. Half of his abdominal wall is missing with exposed viscera and active bleeding. He arrests on arrival and you get him back with an emergency department thoracotomy and aortic cross clamp. In the operating room you start on his abdomen while anesthesia continues to resuscitate with blood products. He has so many injuries you don't know where to begin, but you get to work and are finally gaining ground when the pagers go off again. Seven "urgent surgical" patients are inbound, and your anesthesiologist tells you he just hung the tenth unit of blood, which is half of your total blood supply. All eyes are on you – what are you going to do? Do you continue and exhaust your unit's blood supply on this patient with a low probability of survival? Do you stop and make this patient "expectant," allowing him to die so that you can tend to the other injured patients?

These are the types of decisions regarding the provision, withholding, and withdrawal of aggressive care that you are rarely faced with in civilian practice but will frequently encounter in the deployed setting (Fig. 36.1). You are used to giving your all and doing everything possible for your patients until you have either won the battle or reached the point of futility. In the combat setting you must also give equal weight to your situation, capabilities, and available resources. Are you dealing with a single casualty or are you in the middle of a mass casualty scenario? Is there another facility willing and able to provide the needed care? Do you have the MEDEVAC assets available to get that patient to a higher level of care? Do you have the required expertise, equipment, and training available at your facility to care for this patient? Is your facility at 10% occupancy or is it near capacity with already exhausted personnel? Will this patient require resources that you do not have available, or resources that are scarce and needed for other patients? Not infrequently the answer will be that you cannot provide aggressive care or need to cease aggressive care and manage the patient as an "expectant" casualty. The goal of this chapter is to familiarize you with the common situations and decisions you may face about the level of care to provide, and some key concepts in providing compassionate and competent expectant care.

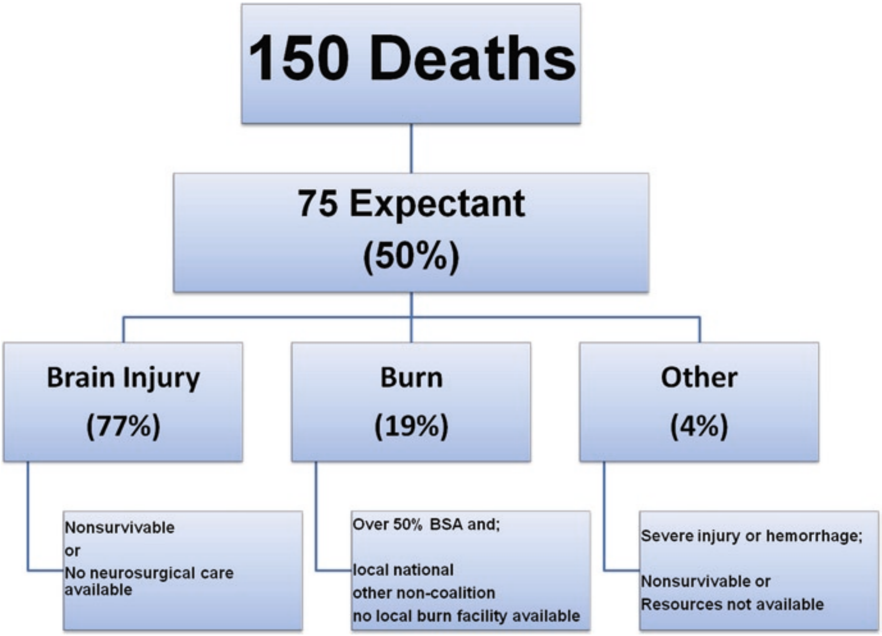

Fig. 36.1 Analysis of 150 in-hospital deaths at a Combat Support Hospital over 1 year. Note that 50% of these were managed as "expectant" and consisted of primarily head injury and burn patients

Combat Care and the "God Complex"

In the movie "Malice," an arrogant surgeon is being sued for malpractice. When questioned about whether or not he has a God complex, he replies "If you're looking for God, he was in operating room number two, on November 17, and he doesn't like being second guessed. You want to know if I have a God complex? Let me tell you something – I AM GOD!" Although this is quite an advanced case, many of us have fallen into this type of thinking at one point or another. There is no faster cure for the God complex than to deploy to an austere environment. You will quickly realize how little your individual skills, talent, and dedication mean when you don't have the level of support and infrastructure to which you are accustomed. It is a sobering moment, but it truly makes you appreciate how much everyone around you contributes and how dependent you are on the entire system to be able to deliver high quality care.

Along these same lines, you may have no significant trauma experience or you may have spent your entire career at a level 1 trauma center. You may be right out of training or be a senior surgeon with decades of experience. Either way, you will have a lot to learn about combat trauma care in general and the specifics of your local facility – all in a very short time. There will likely be some established policies for all aspects of care, including expectant care, that have been developed by your predecessors based on experience and previous mistakes. Learn from those that came before you. There is often a temptation to ignore these "lessons learned" and think that you can somehow do it better than everyone who came before you. With personnel turning over every 6–12 months, this kind of thinking results in cycles of repeating the same mistakes rather than making continual progress and improvement. As a wise sergeant once said to me, "we're not 6 years into our combat experience; we're on our sixth 1-year experience."

Determining Expectant Status

In general, those patients who have injuries that make them unlikely to survive are declared expectant. This definition depends on many factors in any environment but especially where far-forward combat surgical support is delivered. In Afghanistan and Iraq, those local national casualties who sustain burns of >50% body surface area, head injuries with an initial Glasgow Coma Score of <5, and those who sustain blunt traumatic arrest in the field or in the evacuation chain without an easily identifiable and correctable cause are classified as expectant. In fact, the NATO guidelines specifically classify any host nation casualty sustaining either of the former two injuries as expectant and not meeting the "medical rules of eligibility" or engagement. It is very important to review the theater medical rules of engagement (MROE) prior to initiating care of anyone on the battlefield. The MROE are designed to ensure that the maximal numbers of injured patients who can survive are treated based on the medical and logistical resources deployed in support of military operations in any given country. The MROE must also account for the status of the evacuation and medical capabilities of the host nation – whether it is during a response to support earthquake victims in Haiti or far-forward combat operations in Afghanistan.

There are other potential situations where the expectant category can be used. Patients initially selected for treatment may need to be re-triaged as expectant based on changes in the situation (e.g., more casualties arriving, patient not doing well, resources dwindling, etc.), as in the example that opened this chapter. This can be a difficult decision, particularly for providers in the midst of herculean efforts to save a patient. The triage officer, chief of surgery, or hospital command may need to help the involved surgeons reach the decision to cease further resuscitative efforts in these cases. Another situation arises when host nation or enemy combatants require dialysis or other specialty treatment either emergently or long-term and the host nation has no such capability. These patients are considered expectant and are provided comfort care with no escalation. In these instances, the expectant category is similar to making patients DNR/DNI (do not resuscitate/do not intubate) in the less acute setting.

If a service or therapy is available at a local host nation medical facility then early transfer to that facility is warranted. There are situations where a specific therapy (e.g., peritoneal dialysis) has been used in USA or coalition facilities to stabilize host-nation casualties with certain conditions (e.g., acute renal failure) prior to transfer to a host-nation medical facility. Such therapies should be employed sparingly and only after consideration of the ultimate goal of the therapy, the expected short and long term requirements of the patient, and the capabilities of the host nation. The medical rules of engagement are made with regard to host nation capabilities and the likelihood of survival of the patient if that patient were to sustain the injury and be cared for at a hospital in the region where the casualty was injured. On occasion, the highest standards at the best host nation medical facility can be used to guide therapy on a host nation patient at your facility, but only if there is a reasonable expectation that the patient can be transferred to the host nation facility after they are stabilized. Transfer should occur within 48 h of presentation but can occur anytime provided the patient has a reasonable chance of survival.

Some of the biggest challenges you will have are in educating the combat maneuver or line units regarding the expectant patient. One difficulty will be in explaining why you may not be devoting every possible resource to save one of their soldiers who comes in as described at the outset of this chapter – one who requires ED thoracotomy, massive transfusion, etc., and is unlikely to survive no matter what you do. Additionally, non-medical/combat units may not understand what the medical rules of engagement mean and how to execute them to meet the mission without giving the appearance to the local community that you are doing nothing for their injured citizen that they drop off at the front gate of the base. Such a casualty may meet the criteria of having a life, limb, or eyesight injury but cannot be transferred to your higher CSH or Theater Clearing Hospital because the higher in-country medical control says that there is no room at the higher level care facility for the patient. To meet these challenges, medical facility commanders should establish liaisons with maneuver commands (ideally via battalion or brigade surgeons) to open dialogue and foster understanding.

Location of Expectant Care

The intensive care setting provides the best location for care of the expectant patient because it provides near one-on-one nursing care. However, if you only have one ICU/recovery bed and you are busy, this is not feasible. A quiet area away from any busy trauma bays where family (in the case of local nationals) or other unit members can stay with the casualty is a good place, possibly with at least a curtain for privacy. Other locations could be a separate tent, tent section, or room if available. In the case of multiple or mass casualties, the location of care should be spelled out in your unit's mass casualty plan and should be tiered – meaning that the number of casualties presenting requires that the expectant category patients may need to be moved away from the ICU or ER in order to make room for those who can be saved. However, moving them to an isolated, quiet area does not equate to neglecting them, and thus someone from the nursing staff must be assigned to care for them.

The issue of whether to provide care at the current facility or attempt to transfer the casualty to another facility commonly arises. You may find that many units, particularly far-forward facilities, are not fully aware of the limited capabilities or expectant policies of the larger hospitals. If the patient is clearly in an expectant category, that should be communicated clearly to the referring facility. Mandating MEDEVAC missions for expectant patients should be avoided, as transporting expectant patients in high risk environments has the potential to produce unnecessary casualties among MEDEVAC crews. Furthermore, casualties killed in action should not be transported with live casualties, as this can be both detrimental to morale and take up extra space needed to care for the living injured.

Delivery of Expectant Care

A protocol for treating those patients who are classified as expectant should be established and disseminated (Fig. 36.2). Not only should some guidelines be set as to what types of injuries might be called expectant, but the treatment algorithm should be clearly communicated to the care team. The last thing anybody wants is for a patient to die a slow, painful death; neither do you want to give the appearance of performing euthanasia. These scenarios are never spelled out in the official policies or rules of engagement, so it is often up to you to create them. At every level where far-forward surgical care is delivered, provisions for an ad hoc or formalized ethics team should be in place and exercised when necessary. This can be done very simply in the trauma bay with the attending surgeon or team commander quickly reviewing all the known information about the patient, out loud, for all team members to hear. Either the attending surgeon or another team member can bring up the option of the expectant category and all can quickly give input. Alternatively, the team leader can state why they are going to place the patient in the expectant category and set a quick treatment plan and short-order reassessment time to insure that any miraculous changes in patient status or information have not occurred. The expectant patient should be placed out of the way of the busy areas of the intensive care unit or emergency room whenever possible, preferably where family or unit members may spend time with the casualty for the remaining moments of life.

Ideally, a registered nurse is assigned to the patient to monitor for pain and provide comfort. Sometimes this can be difficult, as the patient's family or other care-givers/unit members will not understand some of the movements and vital sign changes that dying patients display. If there are family or friends with the patient we have found it very useful (and emotionally calming) to enlist their help and participation in the dying process. They are encouraged to comfort the patient, touch and talk to them, and to notify the nurse immediately if they feel that the patient is showing any signs of pain or anxiety. Usually, pain and anti-anxiety medications are the mainstays of expectant care. A well-monitored morphine drip

Sample Expectant Care Order Set

Patient Name: ID Number:
Admit to: Expectant Care Area
Diagnosis:
Status: DNR/DNI
Physician: Pager number:

Medications:

1. Morphine sulfate 5mg/10ml (100 mg in 200 ml)
   step 1: 5 mg iv push q5 minutes until comfort or respiratory rate < 20
   step 2: Start drip, hourly rate at the dose required to achieve comfort in step 1
   step 3: If pain or distress, return to step 1 and treat anxiety as in #

2. Midazolam (Versed)
   step 1: 2-4 mg iv push q30 minutes for anxiety/agitation
   step 2: if continued agitation or frequent dosing, start drip at 4mg/hr and titrate

3. Haldol 5-10 mg q10 minutes for continued agitation

4. Albuterol nebulizer q2 hours for wheezing
5. Scopolamine patch 1.5 mg topically BID as needed for secretions
6. Glycopyrrolate 0.1 mg iv q1 hrs as needed for secretions

Treatments:

1. Titrate oxygen for sats > 92% with maximal support of non-rebreathing mask
2. If intubated, extubate when pain and agitation control achieved as above
3. Stopany previously ordered labs or blood draws
4. Stop any previously ordered radiologic studies
5. Change IV fluids to Normal Saline at 10-20 cc/hr as a driver
6. Remove any unnecessary tubes or lines – nasogastric tube, central lines, etc.
7. Turn off all monitor alarms in the patient's room or area
8. Discontinue visiting hours, family/friends to be present as requested
9. Maintain comfortable environment – quiet, temperature, lighting, positioning
10. Call MD for resp rate > 30, discomfort, agitation, or anxiety not controlled by medications
11. Notify chaplain or other religious support as requested by patient or attendants
12. Notify physician and Patient Administration of patient death

Fig. 36.2 Sample order set for expectant and end of life care

with continuous or intermittent intravenous benzodiazepine (midazolam, lorazepam) as needed will usually suffice. Other common options for pain relief are fentanyl or hydromorphone. Anxiolytics/sedatives should be used liberally and include benzodiazepines, dexmedetomidine, haloperidol, or even ketamine. High doses of these medications should not be given expressly to end life (euthanasia), but the principle of "double effect" should guide your care. Give whatever dose is necessary to alleviate pain and suffering (primary effect), even if a secondary effect will be the hastening of death. The goals are allowing the patient to die with dignity and be as comfortable as possible in doing so. However, as the situation develops and changes, expectant patients can become treatable, and thus the care team should continually re-evaluate the patients in this category and make adjustments as necessary.

Spiritual care can be provided anywhere on the battlefield – the US Army Chaplain's Corps are assigned to battalion level units and higher. While religion-specific care is preferable, military chaplains are trained to give spiritual care to patients, unit members and families of those injured and killed. In most host nations, local religious leaders are available to aid with the interpretation of local customs and can provide valuable input on any ethics discussions involving local national casualties who are expectant or being evaluated for DNR status. Sometimes these individuals are employed at the base or airfield you are working on. Others are readily available in the local community but must undergo adequate security screening before being brought on base.

Aftermath of Expectant Care

Patients who are brought into the hospital alive and subsequently die take a heavy toll on providers of all types and experience levels. It is important to know how your people are doing – especially your nursing staff – because they are constantly at the patient's bedside executing the minute by minute care plan. In most of these cases friends or family members are not available, and thus it falls on the nurse to both care for and comfort the patient. Another population to pay particular attention to is your younger hospital staff members – the medics, nursing assistants, operating

Fig. 36.3 Members of a Combat Support Hospital salute a departing helicopter ("angel flight") carrying the body of a fallen soldier

room techs, etc. It is easy to forget that what seems routine to an experienced trauma surgeon or nurse can be emotionally devastating to an 18 year old medic who is suddenly thrust into the chaos of combat medicine.

It is vital to perform a debriefing for events that include mass casualties as well as anytime a patient dies at your facility. While you may have in your mind that the patient's injuries were obviously non-survivable, the rest of the team may have feelings that it was their fault that the patient died or that not enough was done to save them. They may have no idea what you are thinking and thus it is up to the physicians to lead the team in discussing what happened, what could be done better the next time, and most importantly why it was not their fault that the patient died. It is critically important that your people have an outlet to express some of the emotions they are feeling after these events. This will go a long way toward improving morale, mental health, and lessening compassion fatigue.

In-hospital deaths, and particularly those of young and previously healthy soldiers, will and should have a significant impact. You will be surrounded by incredibly dedicated people who have devoted their lives to caring for sick and injured patients. This is not a group that admits and accepts defeat easily or lightly. It is not uncommon to have the entire hospital assemble to honor the evacuation of a patient who died in their facility (Fig. 36.3). It is an honor to work with these people and take care of these patients across all spectrums of injury. This includes recognition of the end of life and providing the best possible care when it is most needed.

Appendix A: Improvise, Adjust, Overcome:

Field Expedient Methods in a Forward Environment

"In the long history of humankind (and animal kind, too) those who learned to collaborate and improvise most effectively have prevailed." Charles Darwin

The ability of modern armies to project fully functional medical assets to the most austere environments is truly remarkable. Despite this, you will never have the level of support, supplies, and modern equipment that you are accustomed to in your home practice. One aspect of military medicine that has not changed throughout history is the ability of talented and dedicated people to improvise, adapt, and overcome. The following is a collection of tips, tricks, advice and improvised techniques from the authors that they have been taught or developed during combat deployments.

Tubes and Lines

If chest tubes run out or you don't have the correct size for children/infants, an endotracheal tube can be used as a thoracostomy tube.

In a pinch – IV tubing can be used to secure an endotracheal tube or cricothyroidotomy tube.

A Foley catheter can be used as a gastrostomy or jejunostomy tube – tape over the balloon port so it is not inadvertently deflated.

A triple lumen central line kit can be used for thoracentesis or paracentesis.

A large central line (cordis) can be placed into the trachea via Seldinger technique for an emergent temporary airway.

A pediatric central line kit can be used for placing an adult radial or femoral arterial line.

The finger of a sterile glove with a hole on the end attached to a chest tube can be used as a temporary Heimlich valve.

Peritoneal dialysis can be performed through a Foley catheter in the peritoneum and an outflow drain (10 mm JP) in the pelvis, with custom-made dialysate from your pharmacist.

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Chest tube on a Heimlich valve attached to a foley catheter bag is more convenient than pleurovacs when transporting.
A rapid emergency airway can be established using a standard IV tubing set – Fig. A.1.
For open ("sucking") chest wounds a vacuum dressing provides an excellent seal and accelerates closure of the pleuro-atmospheric fistula.

In the Operating Room

Sterile gloves can be used as sterile light handle covers.
A sterile gown can be used as a sterile drape for operative procedures.
A petzl headlamp is great for reading and can be used as a backup OR light.
An NGT tube or IV tubing can be used as a temporary vascular shunt.
A Swan-Ganz catheter can be used as a Fogarty catheter in larger arteries.
If you run out of lap pads anything sterile will work for packing: gowns, drapes, towels, gloves.
Cardiac pledgets can be made from pericardium or peritoneum.

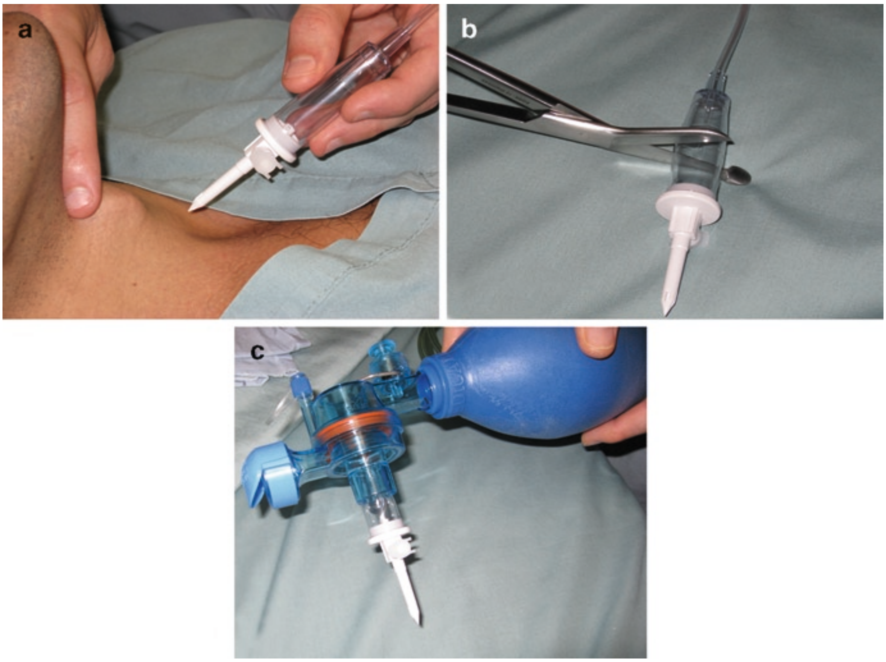


Fig. A.1 Insert the spiked end through the cricothyroid membrane or between tracheal rings (**a**), cut off the back end of the fluid reservoir (**b**), and this should fit well onto the end of an Ambu bag or ventilator circuit (**c**)

Skin staples can be used to temporarily close a cardiac laceration.

Skin from an amputated extremity can be harvested and used for grafting burns.

Vein from the amputated extremity can be harvested and used for vascular patch or repair.

If you are leaving lap sponges in the abdomen, tie them together for easy and COMPLETE removal.

If liver stops bleeding with compression then take down the ligaments and use sterile ace wrap to wrap the liver instead of packing.

Thirty-two to Forty French chest tubes can be used as an aortic shunt in damage control mode. Secure with double umbilical tape ties at both ends.

External fixator pin driven trans-tibial makes a nice field expedient traction pin.

If no scalpel blades – a nice pair of curved Mayo scissors can open any cavity and create any incision. To start simply pinch the skin transversely and cut-then insert scissors and go.

If you need to leave the chest open after a sternotomy – cut the bottom off a plastic bovie holder in a "U-shape" fashion and wedge between the cut edges of the sternum – then apply vac dressing and ioban.

Use 0-silk to quickly ligate perforated bowel. Grab hole with alice clamp or even sections of bowel and mass ligate. Better than umbilical tapes during meatball surgery as umbilical tapes don't slide and hard to get vascular control.

Makeshift wound vac: use sponges from the OR prep kit, NG tube and Ioban.

Tensor fascia-lata from the lateral thigh can be used as a dural substitute to cover exposed brain.

If you need to cut bone and don't have a saw, open the chest tray and use the Lebsche knife. It will work for amputations, sternotomies, cutting ribs.

Make a circumferential wound vac using coban wrapped at both ends on an impervious stockinette.

A bronchoscope or ureteroscope can be used as a choledochoscope.

The abdomino-inguinal incision is an excellent option for gaining control of a proximal femoral artery injury or a distal iliac injury. The exposure is much better than you will get via a laparotomy (Fig. A.2).

If operating in a highly contaminated abdomen and vein not available for an iliac artery repair always keep 1,200 mg of rifampin in the OR (usually comes in 300 mg capsules). The capsules can be crushed and placed in 20 ml of normal saline and a dacron graft soaked for 15 min prior to insertion.

A sterile glove and X-ray cassette cover can make a cover for the Doppler probe and wire for intraoperative vascular evaluations of repairs and distal flow.

Low dose heparin after an arterial repair (300 units/h) if no major contraindication may prevent thrombosis particularly in the highly reactive brachial artery.

Use ventilator tubing from a disposable ventilator circuit set to perform an on-table colonic lavage or rectal washout.

Vascular shunts do not work well in children – repair or ligate. If you repair, use vein graft if possible and use interrupted sutures to allow for expansion with growth.

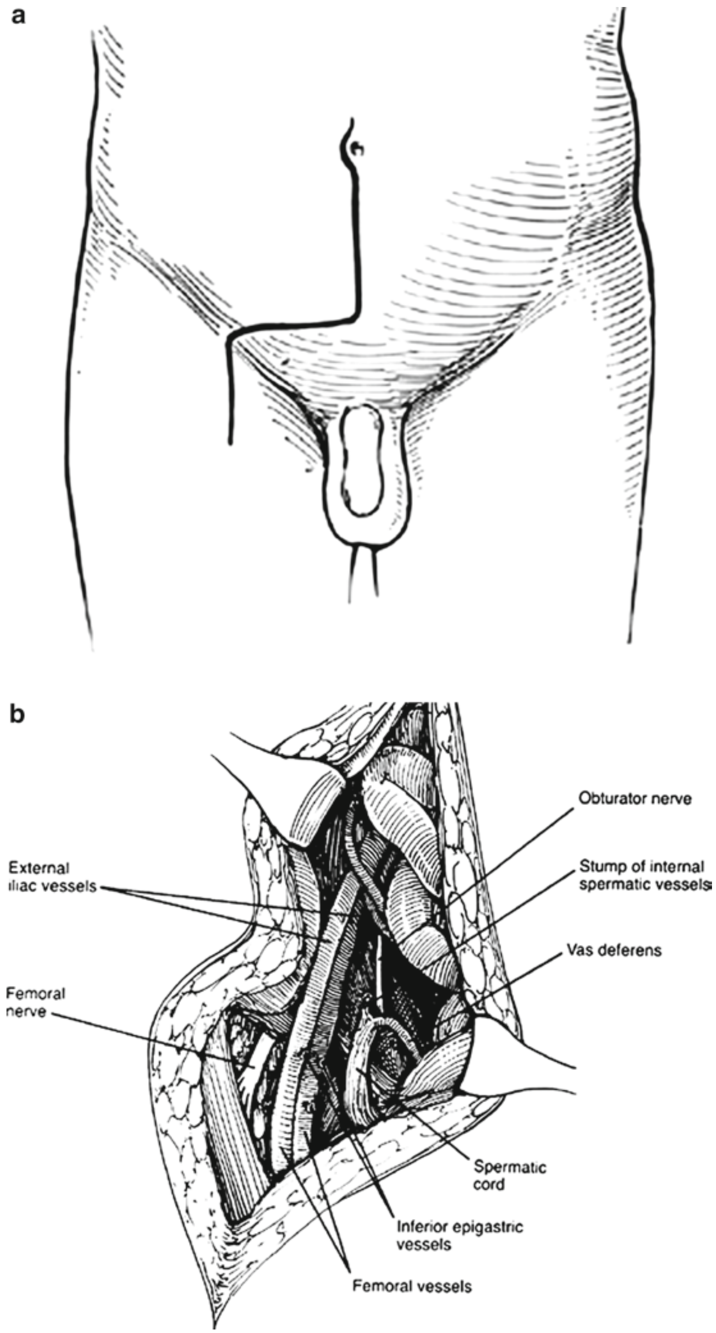


Fig. A.2 The abdominoinguinal incision provides rapid and wide exposure of the mid to distal iliac vessels and the femoral vessels and is ideal for groin or proximal thigh vascular injuries. (**a**) Skin incision, (**b**) surgical exposure gained by division of the inguinal ligament and the inferior epigastric vessels. (Reprinted with permission from Karakousis C, Operative Techniques in General Surgery 2008;10:94–106)

A sterilized glass marble can be used as a spacer following the enucleation of an eye if no ophthalmologic spacer is available.

A hemostat can substitute for a scalpel handle (clamp the blade) if one is not available.

A 3.0 or 4.0 silk on a Keith needle is invaluable for quick “whip stitching” of large wounds when no other instruments are available. It is also faster, as no needle driver is needed, and can close several layers with one pass as opposed to a stapler.

Train your non-surgical colleagues to first-assist on trauma cases. You may not have another surgeon to assist, or it will free up the other surgeon(s) in a MASCAL scenario.

Postop and ICU Care

Placing irrigation fluid and IV fluid in a box and then running a Baer® hugger hose into the box will warm the fluids.

Keep a stock of the meal heating kits that come with every MRE (meal ready to eat). They can be used for warming IV fluids or irrigation.

For clearing airway secretions (particularly in children), mix equal volumes of normal saline and bicarbonate solution and administer/suction via the ET tube. An alternative solution is hypertonic saline mixed with albuterol nebs.

A mist tent (face or whole body) to deliver nebulized treatments or humidified air to help relive upper airway obstruction in infants can be made with wire hangers and clear plastic bags.

If patient warming devices are not available you can use cardboard secured with duct tape to enclose the patient and use a Baer hugger or portable hair dryers to provide warm air.

Lumbar spine support belts or weight-lifting belts can make excellent abdominal binders.

Central venous pressure can be assessed at the bedside using ultrasound (see Chap. 6). Alternatively, measure the vertical height from the sternal notch to the top of the internal jugular vein pulsations in centimeters and add 5 (Fig. A.3).

Bedside assessment of intra-abdominal pressure can be done with a ruler and the Foley catheter (Fig. A.4).

Alternative sites for intra-abdominal pressure measurement are the nasogastric tube (instill 50 cc saline) or a needle inserted directly into the peritoneal cavity.

Ketamine is an often overlooked drug that provides excellent procedural sedation with no hypotension. Dose = 1–2 mg/kg.

Fogarty catheters make great bronchial blockers in the setting of significant hemoptysis with penetrating lung injury or blast lung. Deflate the ETT cuff and advance the catheter to the side of the ETT under direct bronchoscopic visualization until the bleeding bronchial segment is isolated.

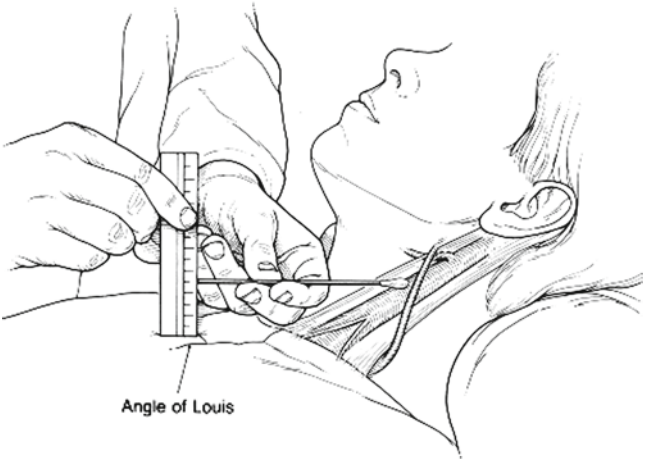


Fig. A.3 Bedside assessment of central venous pressure by physical examination. Reprinted with permission from Felner, J. "An Overview of the Cardiovascular System" in Clinical Methods 3rd edition (Walker et al., editors), 1990, Butterworth Publishers

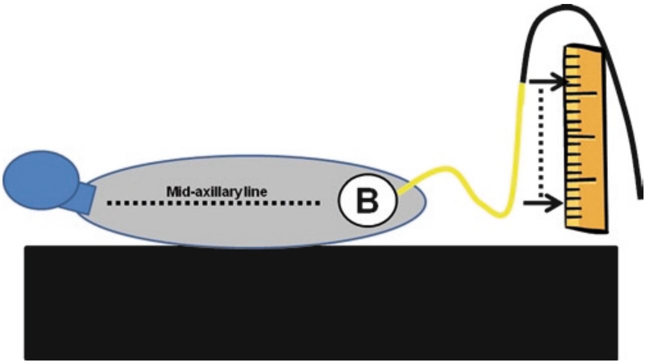


Fig. A.4 To measure bladder pressure without pressure transducers – establish a column of fluid in the catheter by clamping it for 1 h, unclamp and raise the catheter in the air. With the patient supine, measure the vertical distance from the mid-axillary line to the height of the column. Remember to multiply by 0.75 to convert from cmH_2O to mmHg

Miscellaneous

If you are going on a deployment to an austere environment, try to contact the surgeons who are already there. Find out what critical supplies or items (i.e. prosthetic vascular grafts) they don't have and hand-carry them with you.

One of the first things you should do is perform a thorough inspection of your OR supply room. See what you have and don't have – you'll be surprised on both counts.

Canteens can be marked and used as urinals in a mass casualty situation.

Use Excedrin with caffeine far forward to avoid caffeine headaches.

Going days without showers – antifungal cream and baby wipes can come in handy.

Put ambulatory or minimally injured patients to work in MASCAL scenarios. They can apply dressings and hold pressure, help transport patients, and provide comfort.

Always carry a sharpie marker for labeling dressings, marking injuries, or writing medical records directly on the patient.

Use skype for improvised video teleconferencing with stateside colleagues or friends.

Most "disposable" supplies can be cleaned and reused; pay attention to what gets thrown away, a lot can be reused, especially suture.

Wound irrigation with potable water is equivalent to sterile fluid.

Mail a box or foot locker of critical personal supplies (blankets, exercise clothes, reference books) ahead of you. Every pound less that you have to carry on the long trip is a blessing.

Take pictures, record cases and your thoughts, collect data and participate in the many ongoing deployed research projects.

Always remember who's the boss in combat trauma (Fig. A.5).

Finally – SUPPORT YOUR COLLEAGUES, DO THE RIGHT THING FOR THE PATIENTS, AND PASS ON YOUR EXPERIENCE AND LESSONS LEARNED!

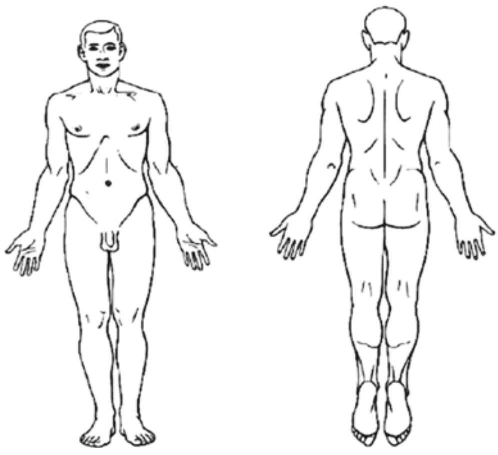
Fig. A.5 Sign posted at the Air Force Theater Hospital, Balad, Iraq

Appendix B: Combat Burn Flowsheet and Order Set

BURN ESTIMATE AND DIAGRAM

Total Area front/back (circumferential)	Adult	one side-- anterior adult	one side-- posterior adult	1st	2nd	3rd	TBSA
Head	7	3.5	3.5				0
Neck	2	1	1				0
Anterior trunk*	13	13	0				0
Posterior trunk*	13	0	13				0
Right buttock	2.5	na	2.5				0
Left buttock	2.5	na	2.5				0
Genitalia	1	1	na				0
Right upper arm	4	2	2				0
Left upper arm	4	2	2				0
Right lower arm	3	1.5	1.5				0
Left lower arm	3	1.5	1.5				0
Right hand	2.5	1.25	1.25				0
Left hand	2.5	1.25	1.25				0
Right thigh	9.5	4.75	4.75				0
Left thigh	9.5	4.75	4.75				0
Right leg	7	3.5	3.5				0
Left leg	7	3.5	3.5				0
Right foot	3.5	1.75	1.75				0
Left foot	3.5	1.75	1.75				0
	100	48	52	0	0	0	0

Age:__________
Sex: __________
Weight: ________



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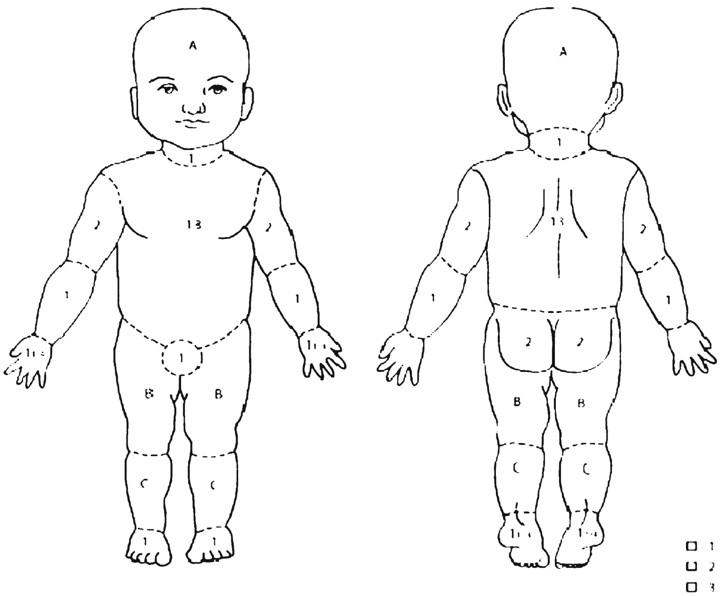
CHILD BURN ESTIMATE AND DIAGRAM

Total Area front/back (circumferential)	1 to 4 years	5 to 9 years	10 to14 years	15 years	1st	2nd	3rd	TBSA
Head	17	13	11	9				0
Neck	2	2	2	2				0
Anterior trunk*	13	13	13	13				0
Posterior trunk*	13	13	13	13				0
Right buttock	2.5	2.5	2.5	2.5				0
Left buttock	2.5	2.5	2.5	2.5				0
Genitalia	1	1	1	1				0
Right upper arm	4	4	4	4				0
Left upper arm	4	4	4	4				0
Right lower arm	3	3	3	3				0
Left lower arm	3	3	3	3				0
Right hand	2.5	2.5	2.5	2.5				0
Left hand	2.5	2.5	2.5	2.5				0
Right thigh	6.5	8	8.5	9				0
Left thigh	6.5	8	8.5	9				0
Right leg	5	5.5	6	6.5				0
Left leg	5	5.5	6	6.5				0
Right foot	3.5	3.5	3.5	3.5				0
Left foot	3.5	3.5	3.5	3.5				0



Joint Theater Trauma System Clinical Practice Guideline

9. Nursing

9.1 Strict I & O and document on the JTTS Burn Resuscitation Flow Sheet Q 1hr for burns > 20% TBSA
9.2 ____ Clear dressing to Art Line/CVC. change Q 7D and prn
9.3 ____ Bair Hugger until temperature > 36° C
9.4 ____ Lacrilube OU Q 6hrs while sedated
9.5 ____ Oral care Q 4hrs; with toothbrush Q 12 hrs
9.6 ____ Maintain HOB elevated 45°
9.7 ____ Fingerstick glucose Q ____ hrs
9.8 ____ Routine ostomy care
9.9 ____ Ext fix pin site care
9.10 ____ Trach site care Q shift
9.11 ____ Incentive spirometry Q 1 hr while awake: cough & deep breath Q 1 hr while awake

10. Diet

10.1 ____ NPO
10.2 ____ PO Diet: ______________________
10.3 ____ TPN per Nutrition orders
10.4 ____ Tube Feeding: ____________________ @ _______ mL/hr OR ____ Advance per protocol

11. Burn Resuscitation (%TBSA > 20%)

11.1 Post Burn 1-8 hrs: LR at _____ mL/hr IV (0.13 mL x Wt in kg x %TBSA)
11.2 Post Burn 8-24 hrs: LR at _____ mL/hr IV (0.06 mL x Wt in kg x %TBSA)
11.3 Titrate resuscitation IVF as follows to maintain target UOP (Adult: 35-50 mL/hr; Children: 1.0 mL/kg/hr)

- Decrease rate of LR by 20% if UOP is greater than 50 mL/hr for 2 consecutive hrs
- Increase rate of LR by 20% if UOP is less than 30 mL/hr (adults) or pediatric target UOP for 2 consecutive hrs

11.4 If CVP > 10 cm H_2O and patient still hypotensive (SBP < 90 mm Hg), begin vasopressin gtt at 0.02 – 0.04 Units/min
11.5 Post burn day #2 (Check all that apply)

____ Continue LR at _____ mL/hr IV
____ Begin __________________ at ______ mL/hr IV for insensible losses
____ Start Albumin 5% at ______ mL/hr IV ((0.3 – 0.5 x %TBSA x wt in kg) / 24) for 24 hrs

12. IVF (% TBSA ≤ 20%): ___ LR ___ NS ___ D5NS ___ D5LR ___ D5 .45NS ___ + KCl 20 meq/L @ ____ mL/hr

13. Laboratory Studies & Radiology

13.1 ____ CBC, Chem-7, Ca/Mg/Phos: _____ ON ADMIT _____ DAILY @ 0300
13.2 ____ PT/INR ____ TEG ____ Lactate: _____ ON ADMIT _____ DAILY @ 0300
13.3 ____ LFTs ____ Amylase ____ Lipase: _____ ON ADMIT _____ DAILY @ 0300
13.4 ____ ABG: ____ ON ADMIT ____ 30 mins after ventilator change ____ Q AM (while on ventilator)
13.5 ____ Triglyceride levels after 48 hours on Propofol
13.6 ____ Portable AP CXR on admission
13.7 ____ Portable AP CXR Q AM

16. Analgesia/Sedation/PRN Medications

16.1 ____ Propofol gtt at ____ mcg/kg/min, titrate up to 80 mcg/kg/min for SAS 3-4.

16.2 ____ Versed gtt at ____ mg/hr, titrate up to 10 mg/hr for SAS 3-4; may give 2-5 mg IVP Q 15 minutes for acute agitation or burn wound care.

16.3 ____ Ativan gtt at ____ mg/hr, titrate up to 15 mg/hr for SAS 3-4; may give 1-4 mg IVP Q 2-4 hours for acute agitation.

16.4 ____ Fentanyl gtt at ____ mcg/hr titrate up to 250 mcg/hr ; for analgesia may give 25-100 mcg IVP Q 15 minutes for acute pain or burn wound care.

16.5 ____ Morphine gtt at ____ mg/hr, titrate up to 10 mg/hr, for analgesia may give 2-10 mg IVP Q 15 minutes for pain or burn wound care

16.6 Important: Hold continuous IV analgesia/sedation at 0600 hrs for a SAS ≥ 4. If further analgesia/sedation is indicated, start medications at ½ of previous dose and titrate for a SAS 3-4.

16.7 ____ Morphine 1-5 mg IV Q 15 minutes prn pain

16.8 ____ Fentanyl 25-100 mcg IV Q 15 minutes prn pain

16.9 ____ Ativan 1-5 mg IV Q 2-4 hrs prn agitation

16.10 ____ Percocet 1-2 tablets po Q 4 hrs prn pain

16.11 ____ Motrin 800 mg po TID prn pain

16.12 ____ Toradol 30 mg IV loading dose, then 15 mg IV Q 8 hrs for 48 hours

16.13 ____ Tylenol _____ mg / Gm PO / NGT / PR Q _____ hrs PRN for fever or pain

16.14 ____ Morphine PCA: Program (circle one): 1 2 3 4

16.15 ____ Zofran 4-8 mg IVP Q 4 hrs PRN for nausea/vomiting

16.16 ____ Dulcolax 5 mg PO / PR Q day PRN for constipation

17. Specific Burn Wound Care

17.1 Cleanse and debride facial burn wounds with Sterile Water or (0.9% NaCl) Normal Saline Q 12 hrs, use a washcloth or 4x4s to remove drainage/eschar

17.2 Cleanse and debride trunk and extremities with chlorhexidine gluconate 4% solution (Hibiclens) and Sterile Water or Normal Saline, before prescribed dressing changes

17.3 Change fasciotomy dressings and outer gauze dressings daily and as needed; moisten with sterile water Q 6 hours and as needed to keep damp, not soaking wet

Physician Signature ______________________ **Date/Time** ______________________

MEDCOM FORM 688-RB (TEST) (MCHO) JUL 07 PREVIOUS EDITIONS ARE OBSOLETE MC V2.00

PATIENT IDENTIFICATION *(For typed or written entries note: Name – last, first, middle initial; grade; DOB; hospital or medical facility)*	Nursing Unit Room No. Bed No. Page No.
	Complete the following information on page 1 of provided orders only. Note any changes on subsequent pages.
	Diagnosis:
	Allergies and reaction:
	Height: ______________ Weight (Kg): ______________ Diet: ______________

Guideline Only/Not a Substitute for Clinical Judgment
November 2008

Appendix C: Resources, References, and Readiness

Combat Trauma References

Emergency War Surgery Manual: This excellent resource covers all aspects of combat trauma care, and can be ordered free of charge (for military personnel) from the Borden Institute. It can be viewed and downloaded in PDF format at: http://www.bordeninstitute.army.mil/other_pub/ews.html.

War Surgery in Iraq and Afghanistan: Case presentations and numerous photos from combat wounds and management in Iraq and Afghanistan. Available for order through the Borden Institute or other commercial booksellers.

Joint Theater Trauma System Clinical Practice Guidelines: As of this writing there are 26 complete guidelines on a variety of topics related to combat casualty care. Internet address: http://www.usaisr.amedd.army.mil/cpgs.html.

General Trauma and Medicine References

Top Knife (Hirshberg and Mattox): The most practical and useful handbook for trauma surgeons available.

Current Therapy of Trauma and Surgical Critical Care (Asensio & Trunkey): A thorough but focused textbook of modern trauma and critical care principles and procedures.

Clinically Oriented Anatomy (Moore, Dalley, and Agur): A basic anatomy text is a must, and this one combines normal anatomy with useful clinical information and pathology.

The ICU Book (Paul L. Marino): A great ICU reference, and go to the website at http://www.theicubook.com for access to a variety of ICU clinical practice guidelines.

The Harriet Lane Handbook of Pediatrics (Custer and Lao): A definitive resource for pediatric diagnoses, management, and medications.

Atlas of Vascular Surgery: Basic Techniques and Exposures (Rutherford): A concise review of vascular surgery techniques and exposure of any vessel in the body.

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Operative Trauma Management: An Atlas (Thal, Weigelt, and Carrico): Step-by-step diagrams of the common and critical trauma operative procedures.

Subspecialty References

Ashcraft's Pediatric Surgery (Holcomb and Murphy)
Surgical Approaches to the Facial Skeleton (Ellis and Zide)
Handbook of Neurosurgery (Greenberg)
Surgical Exposures in Orthopedics (Hoppenfeld)
Emergency Ultrasound (Ma and Mateer)
Emergency Vascular Surgery (Wahlberg, Olofsson and Goldstone)

Internet Resources

Information, pictures, and even videos on almost every topic you might need are now available via the internet. Many of these are open access sites and your medical library can often provide free access to pay-for-service sites. However, you must take into account that your internet access will vary widely in the far forward setting. Even if you are fortunate enough to have reliable internet access, it will typically be much slower than what you are accustomed to. These are some sites that the authors have used while deployed.

MD Consult (http://www.mdconsult.com): access to multiple online textbooks and full text journal articles.

Vesalius (http://www.vesalius.com): detailed anatomy and step by step surgical photos and instructions for a variety of procedures.

Google Scholar (http://www.google.com): free online search engine for medical and scientific information with many links to full text articles or references.

Eastern Association for the Surgery of Trauma (http://www.east.org): features a number of evidence-based clinical practice guidelines for trauma.

Critical Care Medicine Tutorials (http://www.ccmtutorials.com): reviews and tutorials of basic ICU topics and management algorithms.

Trauma.org (http://www.trauma.org): trauma-related tutorials, case presentations, and photos.

Primary Surgery Online (http://www.primary-surgery.org/start.html): Online textbook of trauma surgery by the German Society of Tropical Surgery.

Emedicine (http://www.emedicine.medscape.com): Continuously updated clinical reference covering thousands of medical and surgical topics.

The Amputation Surgery Education Center (http://www.ampsurg.org): Online information and extensive videos of upper and lower extremity amputation techniques.

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