Global Orthopedics

Caring for Musculoskeletal Conditions and Injuries in Austere Settings

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Editors

Second Edition

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To Sherry and Pearl who made all of it possible

– Richard A. Gosselin

To Maryam, Sophie, Michelle, Richard, all my friends at the Hospital and Rehabilitation Centre for Disabled Children (HRDC); Drs. Ashok Banskota, Bibek Banskota, Om Shrestha, Tarun Rajbhandary, Ishor Pradhan, Prakash Sitoula, Abhiram Singh, Saroj Rijal, and Babu Kaji Shrestha; and Drs. Thamer Hamdan and Syed Muhammad Awais

– David A. Spiegel

To Orty, always

– Michelle Foltz

Preface to Second Edition

Why a second edition of *Global Orthopedics: Caring for Musculoskeletal Conditions and Injuries in Austere Settings*?

With the 2014 publication of the first edition of *Global Orthopedics: Caring for Musculoskeletal Conditions and Injuries in Austere Settings*, we were prompted to reevaluate the book's content. Every new mission brought our attention to situations and problems we had not previously considered or included. The proposal by Springer for a second edition has given us the opportunity to make those changes and turn it into a more useful book. We added a chapter on rehabilitation, an essential element in all aspects of orthopedics. Certain chapters have been extensively rewritten either for clarification or to better focus the information for the intended audience: surgeons working in austere environments. This edition also reflects our own experiences treating increasingly more complex trauma cases.

Though the barriers for providing orthopedic care in austere settings remain and continue to pose similar problems as those outlined in the first edition of *Global Orthopedics: Caring for Musculoskeletal Conditions and Injuries in Austere Settings*, we are aware of the expansion of knowledge pertinent to global health and have experienced the successful transfer of highly effective and demanding surgical techniques that only a few years ago would have been considered unlikely or even dangerous under such conditions.

Part of this expansion is due to the targeted surgical information on the Internet, whether through dedicated teaching sites such as the Global HELP, the AO Foundation, or the purposely recorded instructional videos of surgical techniques and presentations. Many of these are far superior and more favorably geared to global audiences than written techniques in textbooks or paywalled journals that do not address the reality of developing countries' health systems. We have added a number of web addresses for PDFs, free content articles, and videos. Over time, we expect this venue for teaching and continuing education to increase in extent and usefulness.

The most profound changes we have witnessed have come from a number of organizations with programs of global collaboration and exchange, pioneered by individuals who have seen around the many limitations and refused to be deterred. Through training, hands-on teaching conferences in the USA and globally, the development of useful instruments, thoughtful mentoring, and nurturing networks, these leaders have tapped into the universal desire of surgeons wanting to do the best for their patients, if only given the know-how and opportunity. In short, these organizations have provided the impetus for the delivery of high-quality, sustainable orthopedic care despite the continued barriers.

We are grateful to the readers of the first edition of *Global Orthopedics: Caring for Musculoskeletal Conditions and Injuries in Austere Settings* and hope the changes and additions in this second edition will add to the growing body of useful information and continue to help guide surgeons working in austere settings.

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Preface from First Edition

The burden of musculoskeletal diseases and conditions in low and middle income countries (LMICs) has increased substantially over the past 15 years, while the resources to address this are grossly inadequate. In particular, the development-fueled epidemic of injuries primarily affects young males during their most productive years, and the resulting disabilities have a profound impact on the individuals, their families, and society as a whole.

The aging of populations in these same countries has unleashed the musculoskeletal co-morbidities of chronic diseases, further increasing stresses on limited health care resources. The consequences can be social, economic, and/or political. Despite evidence of an "epidemiologic transition", in which non-communicable diseases are eclipsing communicable diseases, only 10% of global resources for health care are allocated for conditions that account for 90% of the world's disease burden. Funding for musculoskeletal conditions is negligible when compared with the resources directed to other health problems such as the infectious diseases.

Access to health services is limited for large segments of the population in developing countries, and many of those who present for care do so at a late stage in their disease. This makes the treatment of these "neglected" conditions more challenging, requires more complex and less cost-effective solutions, and often results in undesirable outcomes. In many cases, salvage treatments are all that can be offered. For every orthopedic patient who reaches a clinic or hospital, many more will have first been seen by a traditional healer or bonesetter. Even in district and provincial hospitals, most orthopedic problems are handled by nurses, orthopedic technicians, general practitioners, and general surgeons; orthopedic surgeons are usually found only in tertiary centers in major cities.

The general standards and use of technology in orthopedics in LMICs rarely match those in richer parts of the world, and health services are dependent on the available human, material, monetary, and institutional resources. Wide variations in access to and utilization of health services are seen both between and within developing countries, especially when comparing rural and urban communities. Disparities often reflect a growing gap between the rich and the poor within each setting, rather than a "north-south", "developed-underdeveloped", or "1st-3rd world" division.

Globalization has changed the dynamics of health care and has increased awareness of the inequities in services available in austere environments. This has led to a great interest in global health and international volunteerism, as evidenced by the extraordinary response to recent natural disasters. In addition, institutions from high income countries have developed and promoted programs and initiatives that aim to improve education and services in LMICs. Enhanced access to travel and communication offers unprecedented opportunities to improve orthopedic services worldwide.

Given this information, how can interactions between practitioners from resource rich and resource poor settings lead to better care for patients throughout the world? We cannot overemphasize the value of the exchange of information and experiences between colleagues from these different environments, encouraging the concept of a "two way street". Surgeons from places in which resources are readily available must necessarily adapt their knowledge and skills in a relevant manner when working in austere environments. Challenges include evaluating and treating familiar conditions, such as trauma and infections that present late or with complications that are rarely seen in the West, and unfamiliar conditions, such as osteoarticular tuberculosis, the residua of poliomyelitis, and the sequelae of untreated congenital deformities. Colleagues practicing in resource constrained environments will be exposed during these interactions to problem solving skills and technologies from resource rich environments, and they must determine to what extent the information can be adapted to their needs.

Contextual variables must be recognized and addressed when choosing among treatments. Management must be individualized and adapted to the local environment, taking into account the desires of the patients and their families, the anticipated needs for activities of daily living, and the physical demands of work, the local resources, and the potential for rehabilitation. What may seem an obvious treatment in one setting may be inappropriate or harmful in another, and the differences are often subtle. Our goal is to create a text book that is unique in scope, based on the experiences and insights of authors from a wide variety of settings around the world. This shared endeavor pairs surgeons from resource rich settings who have experience working in austere environments, with surgeons who work daily in difficult conditions in LMICs to make a balanced text that will be beneficial to all practitioners treating orthopedic conditions where resources are limited. This book does not pretend to address all musculo-skeletal conditions, but rather explores an array of commonly seen problems and solutions. There is not much "evidence" on which to base some of the recommendations, other than experience, but more importantly, we hope the principles implied by these recommendations will guide the practitioner to a rational approach. Not one of the authors will be in 100% agreement with what is written. Rather, we have tried to tap into the cumulative experience of all authors, which totals well over 500 years.

The word "surgery" has been omitted from the title, recognizing that the management of musculoskeletal conditions and injuries in austere settings is largely non-operative. While some surgical techniques and approaches are described, this is not the main focus of the book. The primary aim is to provide volunteers or others engaged in elective or relief work in teaching and/or service provision with sound, basic principles and tools for the appropriate and effective management of orthopedic conditions. The needs are great, and a surgeon working in a resource constrained setting will have his or her perceptions regarding the field of orthopedic surgery expanded and enhanced in ways that few other learning experiences offer. We hope in the end, the reader will appreciate the limitations of austere environments, and have acquired the knowledge to address both familiar and unfamiliar conditions in these settings.

A child with paraplegia wanted to play badminton, so a custom frame was constructed in the workshop. While some conditions cannot be cured, something can always be done to improve the lives of our patients (Courtesy of the Hospital and Rehabilitation Centre for Disabled Children, Janagal, Kavre, Nepal)

What Do We Call this Place?

There is no one set of terms that reflects the economic and human realities on the ground that can be used for every situation where a volunteer orthopedic surgeon might travel.

Some divisions that were used in the past are politically outdated, such as third world—a term previously used for countries aligned with neither free market economies nor the communist second world. Most were poor countries and the term remains in the lexicon in an off-hand manner.

The division into developed and developing—the latter sometimes qualified as economically under-developed—has been commonly used and plays into the idea of development as it is practiced by governmental and nongovernmental aid agencies working to upgrade infrastructure, build capacity, and generally improve the lives of people. A variety of spin-offs, such as, "still developing" add nuance, but little concrete information. We use these terms in this text primarily out of habit and for simplicity's sake.

Low and middle income countries (LMICs) is a broad economic term defined by specific country-wide income brackets.Based on gross national income (GNI) per capita in US $, low-income is ≤1,025; lower middle income is 1,025–4,035; and upper middle income is ≥4,036. It is unfreighted with ambiguous or pejorative meaning, but is clumsy and encompasses a wide range of countries and situations that are difficult to place into groups to allow worthwhile comparisons.

Sometimes it is more useful not to talk about countries but to refer to settings or environments. Resource challenged, limited resources, under-resourced, transitional, and under-served are useful descriptive terms of more local conditions. Another term that has gained traction is austere environment. It seems a particularly appropriate term as for most of the countries or settings discussed in the book, austerity particularly affects the surgical fields.

Resources are not limited in the same manner or extent everywhere. Medical practice in LMICs is changing rapidly, and what used to be a rather standard lack of just about everything is being replaced piecemeal with an often unbalanced accumulation of resources that may have little to do with expectations based on gross national income per capita or need, but more on the vagaries of development money, the level and impact of corruption, the strength or weakness of the medical education system, or the presence of a few insightful and diligent people.

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Part I

Introduction

A History of Orthopedics in Austere Settings

1

Michelle Foltz, Geoffrey Walker, and James C. Cobey

With the growth of their specialty after World War II, orthopedic surgeons have worked to develop, expand, and improve orthopedic care and teaching in resource-poor countries. Nongovernmental and governmental organizations, religious and secular charities, and individuals have played, and continue to play, a role in the developing world, establishing and strengthening training programs and providing service. The primary nature of orthopedic injuries and disease, the significant increase in orthopedic trauma as the world relentlessly develops, and the "can-do" attitudes that shape the profession all point to an increasing involvement of Western surgeons in international work.

The history of American organized orthopedic volunteering started in the late 1950s with two groups: the Medical International Cooperative Organization (Medico) and the Orthopedic Letters Club Overseas Program. This was a time of widespread soul-searching by Americans after the 1958 publication of the political novel *The Ugly American*. The stories of official ignorance, arrogance, and misbehavior did not sit well with Americans' notions of themselves. As a counter to this bleak picture, the inspirational books and engaging lectures of Dr. Tom Dooley, one of the founders of Medico, showed that the citizen-doctor-diplomat could change this negative perception.

In 1960 Medico became the medical arm of the Cooperative for American Relief Everywhere (CARE), a broad-based development and disaster relief organization. (In the 1980s the organization became international, changing its name to Cooperative for Assistance and Relief Everywhere.) The two orthopedic organizations interested in international work merged their efforts in the early 1960s, becoming a subgroup of Medico called Orthopedics Overseas (OO) with their own board and earmarked donations for their international programs. The core of dedicated surgeons in OO set up service and training programs in Tunisia, Indonesia, and Afghanistan, among other countries, with the goal of attaining local self-sufficiency in orthopedic care and training.

The seeds for World Orthopedic Concern (WOC) were planted in 1970 during Dr. Ronald Huckstep's world lecture tour to advise on the treatment of children crippled by polio in the developing world. His colleagues agreed that there was a need to improve orthopedic care and training in low-resource countries and envisioned setting up programs similar to those of Orthopedics Overseas under a global umbrella. The first formal meeting of WOC was held in Lagos, Nigeria, in 1977. In 1986 Orthopedics Overseas and the Committee on Orthopedics

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Overseas of the Canadian Orthopedic Association became affiliated with WOC but have retained their national identities.

During its 1978 meeting in Alma-Ata, the World Health Organization (WHO) made the case that primary care programs, rather than specialty programs, would bring the most good to the highest number of people in developing countries. In turn, CARE/Medico decreased support for its specialty training programs, such as OO, to emphasize primary care.

This was not a new controversy. From the start, the founders of Medico differed about whether to promote specialty or primary care programs in developing countries. Today it remains an issue within and among nongovernmental organizations (NGOs) and the funding bodies and foundations that support them. With the increasing sophistication of surgeons in developing countries because of the training and collaboration from many groups and individuals as well as the availability of cost-effective and useful instruments, many aspects of orthopedics, particularly trauma, are now viewed—even by the WHO—as primary care.

Since no small group of surgeons can realistically tackle all the orthopedic needs in the developing world, many organizations and individuals have concentrated their efforts on teaching and training. Besides developing capacity to meet orthopedic needs locally, the personal relationships have fostered continued interaction and have been a major factor in the strong global orthopedic network.

This brings up the questions of who to teach, what to teach, and where to teach. The answers to these questions depend on the particular country and the philosophy of the volunteer or organization.

Some of the most useful and long-term advances in delivering trauma care have occurred by teaching nurses and primary care workers at the middle and lower levels of the health system. Trained to properly manage basic trauma, they can save lives by working through systems, such as Advanced Trauma Life Support (ATLS), proceeding with ABCs, giving fluids, and recognizing life-threatening and limb-threatening situations. In most developing country hospitals, general surgeons are the major providers of orthopedic care, and some training programs concentrate on providing them with the orthopedic expertise to handle common musculoskeletal problems. In some countries, such as Malawi or Mozambique, with a limited population of surgeons, non-physician orthopedic clinical officers are trained to deliver basic orthopedic care, including surgery.

If an organization wants to provide specialized orthopedic training and care, one of the first questions is where to train. In the beginning OO brought candidates for training to the USA. These highly trained surgeons returned home but rapidly became frustrated by the lack of equipment and ancillary help. Governments did not pay for specialized care, and colleagues were mistrustful of the new ideas brought from the outside. Not able to put their skills to use, the newly trained surgeons often returned to the West.

Teaching in the local environment with locally available equipment to care for local conditions seemed a better alternative. This usually involves building training programs from scratch with curricula to address the existing limitations or working within existing institutions. Good programs evolve, increasing in their self-sufficiency as more and more individuals are trained to higher standards.

Another decision is where in a country to train. Most often, and by default, this takes place in the capital, the seat of government, the home of the university or medical school, and the site of the largest hospital with the greatest number of ancillary specialists. But sometimes the government gets in the way and has its own agenda, the university is filled with outsized egos, and the largest hospital in the country becomes a sanctuary of specialty care, out of reach for the average patient with simple but debilitating orthopedic problems.

As more surgeons are trained and as the speed of development accelerates, the substance of what to teach is rapidly evolving. The idea that only nonoperative techniques that were current 40 or 50 years ago are the most appropriate for developing countries has come under considerable debate in the last decade. However, proper reduction and casting techniques as well as the principles of treatment in traction remain the mainstays of most fracture work in developing countries. As Western surgeons increasingly lose their skills to perform such nonoperative treatments, they have much to learn from their peers in developing countries, and volunteering becomes a network of teaching *and* learning.

No matter one's philosophy of how best to treat specific injuries and orthopedic conditions, teaching the basics of clinical orthopedics is the purpose of most training programs. Teaching by example that diligence, compassion, and communication along with a thorough knowledge of the problem and the various solutions is an essential component of orthopedics everywhere.

The history of orthopedics in resource-poor environments is not solely the work of organizations. Individuals—through necessity, the ability to look at problems from novel angles, and unconventional single-mindedness—have made a huge impact in the way orthopedics is practiced in countries with few resources.

The bicycle spokes, and locally manufactured rings and bars that Dr. Gavriil Ilizarov ingeniously fashioned into his external fixators in Siberia in the 1950s and 1960s were the result of having little else to work with. These instruments and protocols have given orthopedic surgeons a new approach to previously poorly understood problems. The Ilizarov system is an important disruptive technology that can be equally as useful in the most sophisticated high-tech center as in the most rudimentary clinic.

When in East Africa and faced with large numbers of joint contractures and deformities in children and young adults from polio in the 1960s, Dr. Ronald Huckstep not only devised a series of successful surgeries to deal with the problems but established workshops and taught people—including those whom he had helped with his surgeries—to make low-cost braces. Despite all attempts to eradicate the disease, polio and its residua remain a problem in some developing countries, and many of the principles of Dr. Huckstep's surgeries are the basis of polio treatment today.

Another approach to orthopedic needs in resource-poor countries is exemplified by Dr. Scott Harrison, through his foundation, CURE International. Combining his expertise as a surgeon, his faith, and his organizational abilities as a businessman, CURE has established orthopedic pediatric hospitals in many poor, developing countries, making them centers of excellence through the specialized training they offer and the surgery they provide (Fig. 1.1).

Fig. 1.1 The bright, clean, welcoming entrance to CURE's Pediatric Orthopedic Hospital in Kijabe, Kenya

The history of Western practitioners working in resource-poor countries cannot be separated from the question of equipment. Some surgeons make it a point to take no donated equipment with them, knowing the problems of sustainability or the lack of experience in treating the complications that such techniques may bring, especially if used without adequate training. Most donations are made with the best intentions, but any volunteer who has walked through a gauntlet of irreparable C-arms crowding already limited space in an operating theater knows that donations have to be realistically considered from many angles.

SIGN (SIGN Fracture Care International) has shown that high-quality implants to treat long-bone fractures can be reliably used by developing country surgeons, working in less than ideal situations, if they are given a sustainable supply and are taught how to use them. SIGN's program combining feedback, mentoring, and networking has produced a new paradigm that has been especially useful in situations where poverty makes effective treatment of certain debilitating fractures extremely difficult (Fig. 1.2).

Providing disaster relief has been a major idea behind orthopedic work in developing countries, but it is one of the most difficult to realize. Few volunteer orthopedic organizations have been able to build, maintain, and put into action all the components that would allow a reasonably equipped orthopedic disaster-assistance team to become immediately operative in the field. Such an organization could be readily staffed by willing volunteers, but only government agencies, the military, and one NGO, Médecins sans Frontières (MSF or Doctors Without Borders), have the necessary logistics to manage such a team. The surgery needed in disaster situations is similar to war surgery, demanding strict adherence to specialized protocols and triage principles that are unfamiliar to many volunteer orthopedic surgeons (Fig. 1.3).

Volunteer orthopedic programs have evolved over the last 50 years. Besides secular, nonprofit programs interested in training, like OO, volunteer programs with various agendas and goals have expanded the field. In organizations whose main goal is teaching, some specialize, teaching surgeons, residents, or nonsurgical clinicians. Some limit their programs to a specific region or country, such as focusing on the orthopedic problems of West Africa or Southeast Asia. Others concentrate on a specific area of orthopedics such

Fig. 1.2 US orthopedic volunteer, Carla Smith, introducing SIGN instruments and technique to surgeons in Nepal

Fig. 1.3 Surgeons from Haiti, Denmark, and Ghana working together under the auspices of MSF, Doctors Without Borders, after the 2010 earthquake in Haiti

as trauma or pediatrics or joint replacement surgery. Some NGOs are religiously affiliated, and many religious charities support programs or hospitals. Some organizations build hospitals or refurbish existing hospitals in order to maintain control. Different philosophies and goals provide a field wide enough for any volunteer to find a place to match her or his needs and skills.

The strength of the past 50-year history of orthopedics in developing countries rests on the work and determination of many surgeons who did not believe that limited resources meant limited results. As more surgeons rise to the challenge of improving orthopedic care in developing countries, this attitude will continue to shape the future and change the face of global orthopedics.

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2 Global Burden of Musculoskeletal Conditions

Manjul Joshipura, Charles Mock, and Richard A. Gosselin

The Burden of Musculoskeletal Injuries

Injury is a major cause of death and disability globally. This is true in countries at all economic levels. There is a misperception that injuries are primarily a health problem of high-income countries. However, injury mortality rates are considerably higher in low- and middle-income countries (LMICs), as can be seen from Table 2.1 [1]. Globally the rates of death from all types of injury combined are 76/100,000/year. This is lowest in high-income countries (52/100,000), rises in middle-income countries, and is highest in low-income countries (103 deaths/100,000), where rates of death are twice those in high-income countries.

These high rates of death are in part due to the rising rates of injuries from increased use of motorized transport combined with less developed trauma care systems [2]. Rates of injury have been decreasing in high-income countries due to injury prevention schemes and improved trauma care. At the same time, rates of injury-related death and disability have been steadily rising in most LMICs and account for 90% of the global injury deaths. As most of the world's people live in these countries, these trends have led to increasing rates of injury globally [2, 3].

For every person who dies from injury, many more suffer from nonfatal injury, leading to temporary or permanent disability. The global data for nonfatal injuries is not as comprehensive as those we have for deaths; however, the existing data show a significant burden of disability from musculoskeletal injuries affecting all economic strata, but it is especially heavy for LMICs [3].

Data on the burden of musculoskeletal injury come from several sources including hospital records and household surveys. Data from the National Health Interview Survey in the United States showed a rate for all extremity injuries of 68/1000 persons/year. This included many minor cases that received outpatient treatment only but excluded strains, sprains, and contusions, which did not receive medical treatment or which did not cause more than a half day of disability [4].

Data on more serious musculoskeletal injuries were obtained from the Healthcare Cost and Utilization Project – Nationwide Inpatient Sample (HCUP-NIS). This showed an incidence of hospitalization (for at least 24 h) for musculoskeletal injuries of 3.5/1000/year (2.7/1000/year for lower extremity injuries and 0.8/1000/year for upper extremity injuries). Fifty percent of

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Table 2.1 Numbers and rates of death from injury by economic status of countries

Economic stratum	Number of injury deaths (000)	Population (000)	Rates (deaths/100,000/year)
Low	850	826,417	103
Lower middle	2903	3,834,641	76
Upper middle	816	999,625	82
High	561	1,076,797	52
Total	5130	6,737,480	76

Source of data: 2008 Global Burden of Disease Study [1]

these injuries were due to falls and 20% to road traffic injuries. Similar data have been reported from other high-income countries [4].

Data from LMICs is limited to a few studies from a few countries; however, even these data are instructive. A survey from Ghana showed a rate of serious musculoskeletal injury (disability time of ≥30 days) of 17/1000/year. It is difficult to draw comparisons due to different methodology, and it is likely that many of these serious injuries would have been treated as inpatients in high-income countries, but injury rates in Ghana are far higher than in the United States [4, 5].

Due to difficulties accessing medical care in LMICs, many of the musculoskeletal injuries go on to poor outcomes (see Chap. 5). The Ghana survey showed that 0.83% of Ghanaians had an injury-related disability that had lasted longer than 1 year and was likely to be permanent. Seventy-eight percent of these disabilities were due to extremity injuries. Such disabilities should be readily amenable to low-cost improvements in orthopedic care and rehabilitation, in contrast to the more difficult to treat neurological injuries that are relatively more frequent causes of disability in high-income countries [6].

Using the available data from high-income countries and LMICs, the Global Burden of Disease (GBD) study [1] has provided some global estimates for musculoskeletal injuries. The GBD study evaluated rates of hospital admission for various nonfatal injuries from road traffic crashes. Table 2.2 shows that the majority of these are musculoskeletal injuries. As with fatal injuries, nonfatal musculoskeletal injuries primarily affect those in LMICs. The GBD estimated that the combined rates of extremity injury from falls and road traffic crashes range from 1000 to 2600/100,000/year in LMICs compared with 500/100,000/year in high-income countries [3, 4].

Table 2.2 The 20 leading nonfatal injuries sustained[a] as a result of road traffic collisions, world, 2002

Type of injury sustained	Rate per 100,000 population	Proportion of all traffic injuries
Intracranial injury[b] (short term[c])	85.3	24.6
Open wound	35.6	10.3
Fractured patella, tibia, or fibula	26.9	7.8
Fractured femur (short term[c])	26.1	7.5
Internal injuries	21.9	6.3
Fractured ulna or radius	19.2	5.5
Fractured clavicle, scapula, or humerus	16.7	4.8
Fractured facial bones	11.4	3.3
Fractured rib or sternum	11.1	3.2
Fractured ankle	10.8	3.1
Fractured vertebral column	9.4	2.7
Fractured pelvis	8.8	2.6
Sprains	8.3	2.4
Fractured skull (short term[c])	7.9	2.3
Fractured foot bones	7.2	2.1
Fractured hand bones	6.8	2.0
Spinal cord injury (long term[d])	4.9	1.4
Fractured femur (long term[d])	4.3	1.3
Intracranial injury[b] (long term[d])	4.3	1.2
Other dislocation	3.4	1.0

Reproduced from Peden et al. [7], Table 2.8
[a]*Requiring admission to a health facility*
[b]Traumatic brain injury
[c]Short term = lasts only a matter of weeks
[d]Long term = lasts until death, with some complications resulting in reduced life expectancy

We only have limited global data on rates of nonfatal injuries, and the data that exist, especially those from hospital sources, likely underestimate the significance of the problem, due to both underreporting and the large number who do not receive formal medical care. There are ongoing efforts to develop better global data on nonfatal injuries, including musculoskeletal injuries. The latest iteration of the GBD study in 2016 showed the same skewed distribution of limb injuries according to economic status [8].

The Burden of Nontraumatic Musculoskeletal Conditions

There are fewer studies on the burden of nontraumatic musculoskeletal (MSK) conditions. The initial GBD study [9], in 1990, showed an estimated worldwide burden of 26,842 DALYs (disability-adjusted life years) (see Chap. 4 for discussion on DALYs) for osteoarthritis, rheumatoid arthritis, spina bifida, leprosy, and polio. This represented 16% of the burden attributable to injuries and 2% of the entire global burden of disease. Updated data from 2004 showed a worldwide burden of 34,017 DALYs, for these conditions, which was still only around 16% of the injury-related burden, but represented 2.5% of the entire global burden [10]. More recent data suggest that in 2010, noninjury-related MSK conditions counted for 4.4% of the global burden of disease, more than doubling in 20 years [11]. Conditions that were not included in the initial study, such as neck and back pain, account for a significant portion of this increase. The 2016 GBD data shows a steady increase to now 5.9% of the global burden of disease, a 34% increase in 6 years [8].

Bone and joint conditions with a significant incidence or prevalence, such as malignancies and infections, congenital abnormalities, developmental abnormalities, and nonrheumatoid inflammatory arthropathies, have not been included in the GBD. Though unaccounted for, it is likely their combined contribution to the global disease burden is significant. An overall aging population and the epidemiologic transition toward noncommunicable diseases will likely see a continuation of this trend for the foreseeable future.

Disclaimer One of the authors is a staff member of the World Health Organization. He and the other authors are responsible for the views expressed in this publication, and they do not necessarily represent the decisions or the stated policy of the World Health Organization.

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3 Emerging Orthopedic Conditions

Richard A. Gosselin and El Hadji Ibrahima Diop

Introduction

As populations in developing countries become more wealthy and live longer, the patterns and types of diseases affecting them also change. Musculoskeletal infections, unaddressed pediatric conditions, and injuries remain the most common problems seen today in orthopedic clinics, as they have in the past. However, successful development and better overall nutrition are significantly modifying the incidence, severity, and underlying causes of these orthopedic conditions. This is most evident in the epidemic of road traffic, farming, and industrial injuries in low- and middle-income countries (LMICs). These injuries, both fresh and neglected, are addressed elsewhere in this book. The other trend is an increase in those conditions less often seen previously: age- and lifestyle-related problems. These may look superficially like the same conditions encountered in a Western practice, but for many reasons, they present as more severe and more complex problems and take a greater toll on individuals, their families, and health systems.

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Inflammatory Diseases

Inflammatory musculoskeletal conditions in developing countries have been present, most likely, forever. Since most are chronic, slowly progressive conditions, they were seldom accounted and had low priority. An aging population and relatively easier access to health care are bringing forth an increasing number of patients with rheumatoid arthritis, ankylosing spondylitis, gout, lupus, and seronegative spondylarthropathies [1]. A clinical examination is rarely sufficient for a definitive diagnosis, although certain findings such as tophi or windswept deformities of MCP joints can be highly suggestive. Plain radiographs, showing classic changes, may help point the clinician in the direction of a specific diagnosis. However, most often, only nonspecific laboratory tests, such as sedimentation rate or C-reactive protein, are available.

The more sophisticated and expensive serologic and pathologic tests necessary for a precise diagnosis are inaccessible, except for the very few who can afford them. The services of a rheumatologist are unlikely to be available. For most patients, this makes little difference since the affordable treatments are usually aspirin, paracetamol/acetaminophen, early-generation NSAIDs, and corticosteroids. Targeted medical treatment with interferon, newer-generation NSAIDs or so-called biologics, and surgeries such as spinal fusion and joint replacement are unavailable to the vast majority.

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Degenerative Diseases

Degenerative joint disease (DJD) can be seen as an almost unavoidable consequence of aging but can also occur prematurely secondary to trauma, congenital conditions such as developmental dysplasia of the hip (DDH), hereditary dysplasias, joint infections, and avascular necrosis. It commonly results from unrecognized or neglected intra-articular fractures or severe ligamentous injuries. When major weight-bearing joints are involved, the disability can be severe and prevent farming or manual labor, with dire economic consequences for an extended family. Severe involvement of the lower spine can be crippling.

The incidence of low-back pain, although still less than the epidemic numbers seen in rich countries, is steadily on the rise [2]. As with many other health conditions, patients tend to present late and in advanced stages of debility, at which time conservative management of weight loss, an exercise regimen, and bracing and/or judicious use of rest and walking aids are less successful. Most patients will have to rely on nonspecific symptomatic management and curtail their activity accordingly. The costs of prosthetic components are usually prohibitive, so arthrodesis may be of benefit in selective cases, by alleviating pain and providing stability (see Chap. 41). This option is rarely attractive to patients because of social or religious considerations.

Metabolic Diseases

Aging directly impacts the incidence and extent of two metabolic conditions: osteoporosis and type 2 diabetes. Osteoporosis is more common in postmenopausal women, a group that represents a steadily increasing proportion of the population in developing countries [3]. It is defined by the WHO as bone mineral density (BMD) <2.5 standard deviations below the average healthy population, whereas osteopenia is defined as BMD between 1 and 2.5 standard deviations below the average. Screening and prevention are usually absent, and most commonly the initial presentation is an insufficiency fracture after relatively trivial trauma. Upper extremity, pelvic, or spinal fractures will eventually heal on their own, with or without long-term disability. When the hip is involved, the morbidity can be significant since most such fractures are treated with prolonged bed rest in traction; the 1-year mortality can be well over 20%. Pain, shortening, secondary DJD, and the need to use a walking aid are common sequelae of malunions or nonunions [4].

The incidence of type 2 diabetes is increasing worldwide and reaching epidemic status in regions such as the Middle East [5]. Ironically this is related to a relatively new nutritional problem in poorer countries: overnutrition and a change from a diet of whole grains, fruits, and vegetables to one with more meat, refined sugars, and more calories in general. These dietary changes contribute not just to abnormal glucose metabolism that can lead to infectious and neuropathic complications of the musculoskeletal system but also to obesity, which in turn accelerates the wear on weight-bearing joints [6] (Fig. 3.1).

Patients over 40 undergoing surgery should have a fasting or random glucose evaluation as diabetes is often undiagnosed or if previously diagnosed is inadequately treated and can lead to perioperative wound complications.

Patients with diabetic foot sores often present late, when osteomyelitis is already present and conservative wound management unlikely to succeed. A Syme or below-knee amputation (BKA) is all too often the end result, after multiple ray resections and partial foot amputations fail. A similar problem is seen with neuropathic arthropathies (Charcot joints), particularly around the foot and ankle where progressive joint destruction leads to bony deformities producing chronic pressure wounds that lead to osteomyelitis (Fig. 3.2). Fusion of neuropathic joints has a high failure rate but should be considered before the wounds develop. Otherwise a BKA is a common outcome.

Fig. 3.1 In many LMICs, those in the middle class, including health professionals, have a high incidence of obesity

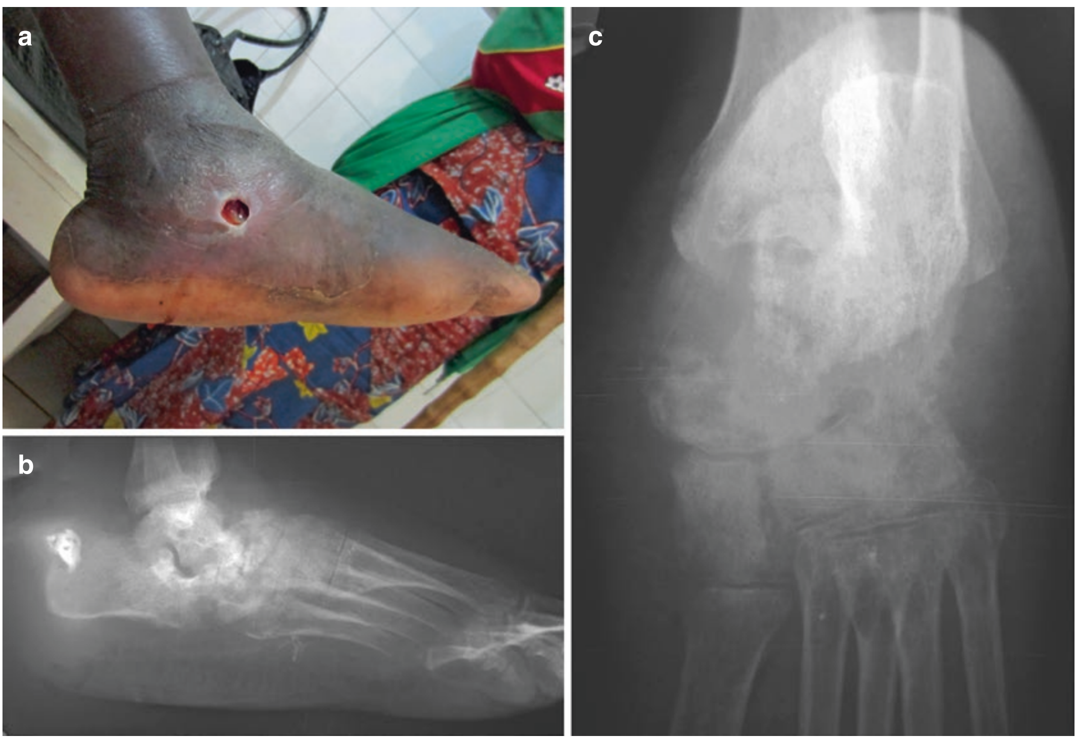

Fig. 3.2 (**a**) Chronic draining sinus of hind- and midfoot Charcot joints from diabetes. (**b**) Lateral X-ray showing destruction of talonavicular, calcaneocuboid, and midtarsal joints with flattening of the longitudinal arch. (**c**) AP X-ray showing osteoporosis, joint destruction, and pathologic fractures

Fig. 3.3 This patient with medullary carcinoma of the thyroid presented with a pathological fracture of the distal femur for which only a knee immobilizer and palliative therapy could be provided

Neoplastic Disease

Primary or secondary (metastatic) neoplasias of the musculoskeletal system increase with age (see Chap. 42). Again, because of late presentation, the vast majority of patients are beyond hope of cure (Fig. 3.3). The unavailability of adjuvant treatments, such as chemo- and radiation therapy, compounds the problem. Metastatic disease is the most common of the bony neoplasms, and the habitual primaries from the lung, breast, and prostate all increase with age.

A pathologic fracture is a common presentation for neoplastic tumors. Faced with the lack of adjuvant modalities and since the fracture has no intrinsic potential to heal, palliative surgery for pain control is usually the only treatment option. If methyl methacrylate is available, internal fixation with curettage and cement stabilization is the best treatment. The fixation should be rigid enough to last longer than the patient's anticipated life expectancy, not always an easy assessment. If cement is not available, fixation is best achieved by one sometimes two long plates or a statically locked IM nail of the largest possible diameter. Some surgeons object to nailing because of the possibility of seeding neoplastic cells distally in the canal, but for most patients presenting late, this is a moot point.

It is clear that the burden of age-related musculoskeletal conditions is rising and will continue to do so for the foreseeable future. This will impact heavily on the decision-making process when planning future allocation of scarce resources.

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4 Cost-Effectiveness of Orthopedic Surgery in Austere Environments

Richard A. Gosselin

Surgery has long been the neglected stepchild of global health due to the commonly accepted and unquestioned notion that it is not cost-effective compared to better studied problems such as malnutrition, infectious diseases (HIV, malaria, TB), or maternal and child health (at-risk pregnancy, vaccination) [1] and relies on resources that are too specialized to be part of the basic health-care package for low- and middle-income countries (LMICs). This concept is increasingly being challenged in new studies that use the same methodologies and metrics that are used to show the benefits of other interventions and that were previously used to exclude surgical care [2–4].

Development has brought about a general increase in life expectancy with its attendant chronic diseases, while the rapid motorization of transport and mechanization of farming and industry have fueled an epidemic of high-energy injuries. Because of these irreversible changes, the need for surgical care is growing globally and will likely accelerate, although the true unmet need is unknown. What is known is the inequity in the distribution of surgical care: more than one third of the world's population live in low-income countries (LICs), yet they receive only 3.5% of the global surgical volume [5]. The multitude of studies spawned by the Lancet Commission on Global Surgery have confirmed this: 5 billion people lack access to safe and affordable surgical and anesthesia care, and 143 million additional surgical procedures would be needed yearly to answer the unmet need (www.lancetglobalsurgery.org). There is no longer any doubt that investing in surgical and anesthesia care is very cost-effective.

A cost-effectiveness analysis (CEA) is an analytical technique or tool that correlates the effectiveness of a health intervention to its costs. It is but one tool that health systems managers and public health policy makers use for the allocation of scarce health-care resources, as they are also bound by political, moral, and ethical imperatives, both locally, nationally, and internationally. The technical advantage of a CEA is that it allows comparisons of different interventions using the same units of measurement, also called metrics. Many such metrics exist. Simple examples are dollars spent per life saved or dollars spent per complication averted, while more complex examples might add quality of life (QoL) components.

Composite metrics aim to capture different dimensions of a given condition into one summary measure and are widely used in cost-effectiveness analysis. Quality-adjusted life year (QALY), health-adjusted life expectancy (HALE), and disability-adjusted life year (DALY) are such measures. The Global Burden of Disease study (GBD) from the WHO, World Bank, and Harvard School of Public Health introduced the concept of DALY and used it as

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their metric of choice to determine the health burden of dissimilar diseases and conditions. The DALY is the most widely used metric within the political, economic, and social arenas of global health [6]. It is beyond the scope of this text to analyze its pros and cons, except to say that it does not meet with unanimous approval by all actors.

The DALY, like other composite metrics, is applied to populations not individuals and is the equivalent of 1 year of life lived in less than perfect health. It measures a condition that is to be avoided or minimized, as opposed to a QALY, which measures a positive goal or outcome. The DALY summarizes into one measure the two fundamental components of any disease or condition: mortality and morbidity. Premature mortality is measured in years of life lost (YLL) attributed to a given disease or condition, and morbidity is measured in years lived with disability (YLD) attributed to said disease condition. DALYs are the sum of YLLs and YLDs for a particular condition and thus represent its health burden.

As stated above, DALYs measure disease within a population. In the example of diabetes, an individual cannot be both dead and blind from it. However, to give a more accurate idea of the health burden of diabetes within a population, those living with the various disabilities caused by the disease are measured and added to the number who died prematurely from the disease. DALYs allow global or regional burdens of disparate diseases such as TB, ischemic heart disease, melanoma, or clubfeet to be measured and compared.

Other composite metrics, such as QALYs and HALEs, are used for different purposes by different organizations, seeking answers to specific questions, in various settings. For example, insurance companies, hospital management, or NGOs might measure their respective levels of success or failure in any one setting by a different metric.

Using these metrics, cost-effectiveness analysis refers to the amount of burden from condition X that can be averted by intervention Y at cost Z. In short, a CEA correlates the costs to achieve effectiveness of treatment Y on condition X and is calculated in dollars, (euro, yen, etc.) per DALY averted. This levels the playing field, making CEAs of such diverse programs as immunizations, tobacco prevention, or cataract surgery comparable since they are all measured using the same metric: dollar per DALY averted. The reader is referred to the GBD study for methodological details [6].

Only with the second edition of the *Disease Control Priorities in Developing Countries* (www.dcp2.org) in 2006 were surgery and its cost-effectiveness deemed deserving of a chapter [7]. Estimates of DALYs averted for the studied surgical interventions varied by region but were in the same ballpark: between \$35 and \$90 per DALY averted in LMICs at the district hospital level. These numbers came as a big surprise to most analysts and earned the unexpected "very good buy" recommendation from health economists. The third edition, published in 2015, is a collection of eight separate books, one entirely on essential surgery. It strongly reinforces the premise that essential surgical care is very cost-effective (www.dcp3.org).

Since this publication an increasing body of evidence has been published, supporting this recommendation: \$11/DALY averted in a general hospital in Bangladesh performing general surgical and obstetric procedures [2]; \$38/DALY averted in a general surgical, orthopedic, and pediatric hospital in Sierra Leone [3]; \$78/DALY averted in a district trauma hospital in Cambodia for IM nailing femur fractures [4]; \$9/DALY averted for cataract surgery in India; and \$13/DALY averted for hernia surgery in Ghana. Though these costs are slightly more than the \$10/DALY averted for measles immunization or the \$15/DALY averted for insecticide-impregnated mosquito nets for malaria prevention, they compare favorably with antiretroviral therapy for HIV at around \$400/DALY averted or the \$500/DALY averted for tobacco prevention programs.

Certain surgeries in developing country settings turn out to be not only more cost-effective than many of the widely supported and politically correct nonsurgical public health initiatives, but when compared with procedures done in the USA—estimated $3800/DALY averted for a tibial nailing of a 20-year-old male or $48,000/DALY averted for total hip replacement in a 60-year-old male—they look to be veritable bargains.

More research is under way, and new or better methodologies are being developed to further define the surgical procedures that are cost-effective in resource-poor environments. This is a good example of how a CEA can make a strong argument for those advocating the inclusion of basic surgical care into the primary health-care armamentariums in developing countries, especially considering the need for surgical treatment of various acute and chronic conditions that will continue to increase for the foreseeable future.

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5 Barriers to the Delivery of Orthopedic Care

David A. Spiegel and Stephen W. Bickler

Introduction

Inadequate access to surgical care results in considerable morbidity and mortality, especially for marginalized segments in low- and middle-income countries (LMICs) [1–7]. Surgery has traditionally been neglected as a public health strategy due to the perception that it is costly and resource-intensive and benefits few within a population. This attitude appears to be changing slowly. Over the past several years, surgical care has received greater attention as a public health intervention in LMICs, leading to a Lancet Commission on Global Surgery (2014) [1], an entire volume of the *Disease Control Priorities in Developing Countries* dedicated to surgery (2015) [2], and by a resolution at the 68th World Health Assembly titled "Strengthening Emergency and Essential Surgical Care and Anaesthesia as a Component of Universal Health Coverage" (2015) [6].

While most visiting surgeons to developing countries will interact with colleagues practicing at the tertiary level, surgical service delivery is commonly fragmented at the systems level, with the majority of patients receiving treatment from traditional healers and nonsurgical practitioners in both the private and public sectors. It is important to at least be aware of the variables affecting access to and use of health services.

A Conceptual Framework

In general, barriers are grouped according to (1) social/cultural, (2) financial, and (3) structural restraints [8]. Services must be physically accessible, available, affordable, and acceptable. The Lancet Commission has described "three delays": seeking care, reaching care, or receiving care [1].

One approach for identifying and addressing the various barriers is based on the World Health Organization's (WHO) conceptual framework for a health system. This focuses on the individual's use of services (demand side) and six building blocks on the system (supply side): governance, financing, service delivery, human resources, medicines and technologies, and information [9, 10]. Interventions directed towards one building block of the supply side affect the others and are highly contextual (Table 5.1).

With respect to governance, few developing country health ministries include surgical care in their national health plans, and a lack of political

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Table 5.1 Barriers to the delivery of orthopedic surgical services

		Potential barriers			
Individual		Age			
		Gender			
		Education			
		Religious or cultural beliefs			
		Financial concerns	Direct costs (out-of-pocket expenses)		
			Indirect costs (time off work)		
			Cost of travel to health facility		
		Fear of anesthesia or surgery			
Health system	Governance	Policies			
		Oversight			
		Regulation			
		Resource allocation			
	Service delivery	Lack of human resources	Insufficient numbers		
			Inadequate distribution (urban vs. rural)		
			Education and training	Orthopedic surgeons	
	Human resources			Other providers	General surgeon
					General MD
					Paraprofessionals
	Medicines and technologies	Inadequate infrastructure			
		Inadequate physical resources and supplies			
		Inadequate mechanisms for transportation and referral			
	Financing	Insufficient governmental allocation of funding			
		Dependence on out-of-pocket expenses			
		No protection from catastrophic spending			
		No risk pooling or insurance schemes			
	Information	Inadequate data on the burden of orthopedic diseases (local, regional, national, global)			
		Inadequate information on availability of services (infrastructure, human, physical resources) at the facilities level			
		Lack of monitoring capability (disease burden, service availability, quality/outcomes)			
		Inadequate communication between central and peripheral levels of health system			

support hampers efforts to improve surgical care. Many countries are now developing or revising national surgical plans in response to the resolutions and information in the above noted studies, but implementing these policies is challenging and requires extensive changes within each health system, or else they will remain merely aspirational. Regulations or guidelines for surgical training and scope of practice, certification, maintenance of certification, and continuing medical education are often lacking.

Service delivery, human resources, and medicines and technologies are tightly interrelated when considering access to surgical care. Deficiencies in infrastructure and physical resources or supplies may limit the availability of or readiness to deliver services [1, 2, 9–12]. Recognizing that the expectations for service delivery vary depending on the level of health facility (district vs. secondary vs. tertiary), a package of "essential" surgical services should be universally accessible at each level.

These services should be aimed at conditions or diseases for which (1) there is a large public health burden, (2) the treatment is highly successful, and (3) is cost-effective [13] (see Chap. 4). Examples of "essential" orthopedic services include irrigation and debridement for osteomyelitis and open fractures, nonoperative treatment of common fractures and dislocations, splinting and casting, application of skin or skeletal traction, and amputation. The WHO has promoted essential surgical services, including orthopedics, through their Emergency and Essential Surgical Care Project (EESC) and a Global Initiative [3, 5, 14].

Deficiencies in human resources include an inadequate number and imbalance in the distribution of trained surgical providers and variation in training and education. Task shifting, in which surgical care is delegated to non-surgeon doctors or health professionals without a medical degree, has become a popular strategy to rebalance some systems.

A critical link within the health system building blocks is the health information system (HIS), which is responsible for data collection, data analysis, and the dissemination of information. HIS deficiencies include limited information on the burden of surgical diseases and the availability of surgical services. The absence of such data and a lack of metrics for monitoring services, patient outcomes/safety, and the functioning of surgical systems inhibit the understanding of orthopedic needs, educational requirements of caregivers, service availability, and quality of services delivered.

With regard to financing, both the direct and indirect costs (lost work time, transportation costs) of medical care can stress a family's resources. Many families are pushed below the poverty line each year due to out-of-pocket medical/surgical expenses. Few low-income countries allocate sufficient funds to cover even the most basic health package, let alone curative services. As such, a large percentage of these are provided by the private sector at high prices or through a host of charitable organizations.

Neither morbidity and mortality nor the availability of cost-effective interventions explains the differences in the local attention particular health issues receive [15]. These differences can be related to the power of the actors, political contexts, the power of the ideas behind the issues, and the nature of the issues themselves [15].

Though the WHO's conceptual framework can be used to identify challenges of advocating for care, it is limited by a paucity of data on the burden of surgical diseases coupled with public misperceptions concerning the ability to deliver and the costs of surgical care in austere environments. Fragmentation within the medical and surgical communities concerning how to address this burden and position the issue publicly has failed to capitalize on policies such as the Millennium Development Goals [15].

Improving access to and use of orthopedic services requires a multidisciplinary effort. Increasing the awareness of the burden of musculoskeletal diseases will only happen through better epidemiological research and the development of advocacy networks, including those formed by surgeons from resource-rich areas who, while working in resource-limited areas, see firsthand the need for change and take action. Solutions must be relevant and aimed at strengthening the health system. Monitoring patient outcomes and health system functions with suitable metrics will help guide the process.

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6 Teaching and Educational Resources

Michelle Foltz

Teaching

Any orthopedic outreach situation in a resource-limited environment provides a number of opportunities for teaching, and few of them require the volunteer to be an academic or have a computer full of PowerPoint presentations. The wards, OPD, and operating rooms are great venues not only for teaching but are opportunities to better understand the local surgical problems and the barriers faced at all levels in delivering orthopedic care. The audience includes not just surgeons and residents but also nurses and techs and even the cleaners. In some countries nursing is a step to medical school, and in his home village, the ward cleaner is the local doctor (Fig. 6.1).

How things are discussed is as important as what is discussed. Open discussions in which all questions are considered while going through decision-making steps out loud can leave lasting impressions and are productive ways of teaching. Showing respect for the patients and members of the team, as well as their opinions, opens the discussion further. Manners count.

Many volunteers think teaching means trying to pass on a vast amount of detailed knowledge, and the more facts given, the bigger and better the impact. Our greatest impacts often come from simple gestures and the seemingly inconsequential. Anyone who has worked with young surgeons, even in a nonteaching position, knows they watch and judge everything a volunteer does. A few days after showing and explaining some small maneuver to facilitate a fracture reduction, it is probable this young surgeon will put your methods into action and explain it to another colleague, using your same words and reasoning. This sort of teaching may well improve patient care better than any lecture detailing a classification system that cannot be put to use in the present setting or is immediately forgotten.

Teaching organizational skills seems far removed from a typical orthopedic volunteer agenda, but such skills are sorely lacking to some degree and at various levels in most hospitals or orthopedic departments in developing countries. In some cultures people do not think they have any control over events and never devise risk management systems to prevent untoward consequences. Hospitals may lack the infrastructure that demands organization, or the existing processes are ineffective. We can help organize OR instruments, set up surgical safety plans, and offer protocols that suit their needs. Those would truly be lasting contributions.

When volunteers are tasked with formal teaching, they should find out the level of instruction expected and what information or skills are expected. Some organizations have training programs directed at specific providers, with syllabi and approved teaching materials. Discussion with previous volunteers or the administrators of

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Fig. 6.1 Informal teaching with surgeons, OR and ward nurses, and physiotherapists

the volunteer organization will help determine what would be useful. Canned PowerPoint presentations copied from the Internet are usually irrelevant and show a lack of imagination and effort. Instructive, entertaining, and pertinent lectures—PowerPoint or scrawled on a white board—given with humor and experiential knowledge are another story.

Most volunteers from high-resource countries have been exposed to different ways of teaching by numerous, enthusiastic teachers. Among the limited resources in many developing countries are good teachers and productive, uncorrupt systems of teaching. In some countries and cultures, teaching is fraught with ambivalence: if too much information is given to the student, he will surpass the teacher and steal the patients. Knowledge is power in such a zero-sum world and is best if not shared too widely.

In such places there is little opportunity to learn how to teach. Surgeons are taught by watching, often becoming technically skillful operators, but when in a position to train may be unable to put the ideas of why, how, and when, not to mention judgment within reach of a resident or trainee. Volunteers can help teach the teachers by framing each patient encounter into a teaching and learning situation.

Good teachers listen. Good teachers ask for advice, are humble, and secure enough to say they do not know what to do or are not comfortable doing a certain procedure. By such examples of professionalism, they will teach more than just orthopedics.

The ultimate in teaching is an exchange of ideas, not simply a one-way dissemination of information. Even in programs that are strictly service-oriented, skills and ideas will be left behind, and the volunteer will have learned aspects of orthopedics he or she had not expected. Just as important are the personal, professional relationships one establishes. They become a conduit for further exchange that can last a lifetime.

Educational Resources

Donated books are welcome teaching aids, but bring the right ones and make sure they go to the right person. In many settings textbooks are limited and are prime targets for theft. As a consequence libraries may be locked with limited access. At some universities—where books are not readily available and the professor is the authority whose views become standard practice for the institution—the culture of referring to books or journals or looking things up is weak or nonexistent.

In settings where books or journals are limited, the culture of how to read scientific literature, evaluate its validity, and put it to use may have never been taught. A volunteer can bring classic or review articles or download them from the Internet and distribute copies for discussion or bring e-libraries on flash drives to distribute.

In settings in which e-books are abundant, usually pirated, local surgeons may be more interested in practical knowledge: how to approach a problem, thinking through the pathology in a systematic and logical way, suggesting solutions with pros and cons, and having backup plans. A surgeon revisiting a hospital or training program will have the advantage of learning what is needed and be prepared with appropriate materials on later visits.

The Internet is open at a more egalitarian level than guarded libraries or pricy textbooks. Smart phone usage and cell phone coverage have expanded exponentially in many austere environments since the first edition of this book, making the Internet a major venue for surgeons in low- and middle-income countries (LMIC) to access techniques and find treatments. An orthopedic topic or procedure typed into any search engine will bring up a wide offering of videos and downloadable pdfs. VuMedi (https://www.vumedi.com/orthopedics/) is one of many platforms that provide free up-to-date content including webinars, videos, and case studies from universities, individuals, and industry.

AAOS and the orthopedic subspecialty societies and their publications provide educational materials and videos. *JBJS Open Access*, *JAAOS Global Research and Reviews*, *OTA International* (Orthopedic Trauma Association), and *The Open Orthopedics Journal* are aimed at the global orthopedic audience.

Social media platforms such as WhatsApp, Yammer, and Facebook support topic-specific chat rooms or groups to share cases or specific problems.

Younger surgeons should be able to maneuver around the web with ease, leaving older surgeons and those who are not easily conversant in a major global language, with the sense that it is confusing and the information spurious. A volunteer spending a couple of hours at an Internet café with a technophobe colleague can open his mind to the professional and personal uses of this marvelous tool.

Realizing the Internet's potential in low-resource countries, the World Health Organization and major book and journal publishers created HINARI, Health InterNetwork Access to Research Initiative (www.who.int/hinari/) in 2002. National universities, research institutes, professional schools, teaching hospitals, government offices, and national medical libraries in most low-income and some middle-income countries can apply for free or low-cost access. HINARI's goals are to promote intellectual rigor through the wide scope of available material, provide the basic materials for research, improve clinical treatment and in turn patient health, and support the global expansion of knowledge.

Ptolemy (www.ptolemy.ca) is a partnership involving the University of Toronto; the Association of Surgeons of East Africa (ASEA); the College of Surgeons of East, Central and Southern Africa (COSECSA); and the Canadian Institutes of Health Research (CIHR). Through its website the medical library of the University of Toronto is accessible to the participating organizations and their members.

HighWire Free access to Developing Economies from Stanford University (http://highwire.stanford.edu/lists/devcon.dtl) offers a number of orthopedic journals from those accessing the site from developing countries.

Global HELP (GHO) (global-help.org) provides free or low-cost publications and videos as a cost-effective method to improve sustainable health care in LMICs. GHO's focus on surgery, pediatric orthopedics, and pediatrics is motivated by the large number of children in LMICs and the potential such knowledge has to prevent disability and provide long-term benefits. GHO's publications are specifically selected for their pertinence to teaching and learning in low-resource environments, making them extremely useful and accessible teaching aids for any volunteer.

Through their foundations, industry has stepped up to support volunteers, nongovernmental organizations, surgeons, and allied professionals working in austere environments. The AO Alliance Foundation (www.ao-alliance.org) is building an extensive program to improve trauma and fracture care in sub-Saharan Africa and Asia through education, fellowships, clinical research, and clinical infrastructure support.

Some of the most far-reaching initiatives addressing orthopedic trauma in LMICs have come through IGOT (Institute for Global Orthopedics and Traumatology) and SIGN (SIGN Fracture Care International). These two organizations working alone and together provide surgical training through conferences, hands-on cadaveric practice, and networking at their bases in the USA and in training sessions in developing countries. IGOT www.igotglobal.org/) focuses on an academic approach, encouraging research on trauma in LMICs. SIGN (https://signfracturecare.org/) provides implants to improve fracture management, supported by a team of engineers and an extensive database. Both organizations have been instrumental in changing the perceptions of orthopedic needs and improving the ability to treat trauma by unleashing the potential of surgeons in austere environments.

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Resources

1. www.youtube.com – a general site for surgical and technical videos.
2. Wheeless' textbook of orthopaedics www.wheelessonline.com free online textbook.
3. www.orthobullets.com a collaborative web site with videos, techniques, cases, post and venue for groups.
4. https://www.thelancet.com/journals/langlo/onlineFirst Lancet Global Health – a monthly free on-line journal focusing on global health issues.
5. www.passioeducation.com from Washington University, St. Louis, specializes in videos detailing clinical evaluation and surgical treatment of nerve injuries and neurological conditions.
6. www.ota.org – web site of the Orthopedic Trauma Association with a large library of free videos showing surgical and non-surgical techniques of trauma management.
7. https://www.POSNAcademia.org – the education venue of the Pediatric Orthopedic Society of North America with a selection of videos on pediatric orthopedic topics.
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7 Equipment and Supplies

Richard C. Fisher and Dominic Awariyah Adondaa

Introduction

Orthopedics is a gadget-rich specialty. The list is long: dressings, plaster and fiberglass casting supplies, traction equipment, pins, intramedullary rods, plates and screws, prosthetic joints, prosthetic limbs, and crutches.

In 2003, a grant administered through Health Volunteers Overseas provided funds to send an experienced operating room technician to large teaching hospitals in five different developing countries. He inventoried the orthopedic instruments and implants and set up an inventory control system with the local operating room personnel. The goal was to establish a method of guiding both equipment purchases and donations to maintain functional sets of compatible instruments and implants that would be available when needed. He spent 3 months on the project, but by the end of the following year, little evidence remained of his efforts.

Maintaining a constant supply of functioning orthopedic equipment is a challenge in all environments, just more so in those with limited resources, where the logistics are difficult and distances long with poor transport. Operating room personnel are often nonspecialized or are rotated between services. This breaks the continuity of the system and the knowledge chain needed to manage the large number of orthopedic implants and instruments. Technically, complex equipment handled by untrained personnel leads to frequent breakage, rendering it useless when repair and maintenance services are unavailable (Fig. 7.1). When instrument sets are kept in wrapped sterilized packs, it is impossible to know if the contents are complete without breaking the sterility (Fig. 7.2). Opening them only as the case begins, it is often too late to make changes. In places where the patient must purchase implants in an off-site location, there is little control of the quality or availability.

Hospital budgets routinely underfund orthopedic departments and may postpone purchases until another funding cycle. Purchasing departments are not run by surgeons or medical personnel, and the agent often chooses lower-cost suppliers who sell equipment that is not compatible with current systems or buys inappropriate items from friends, pocketing a kickback. Guiding donations is difficult as it may require saying "no" to some inappropriate items while waiting for more useful ones, which may never arrive. Equipment, whether purchased or donated, without local maintenance availability usually has a short life span. Items such as power drills, arthroscopy sets, and x-ray machines end up with other useless equipment as baggage, clogging hallways or equipment rooms (Fig. 7.3).

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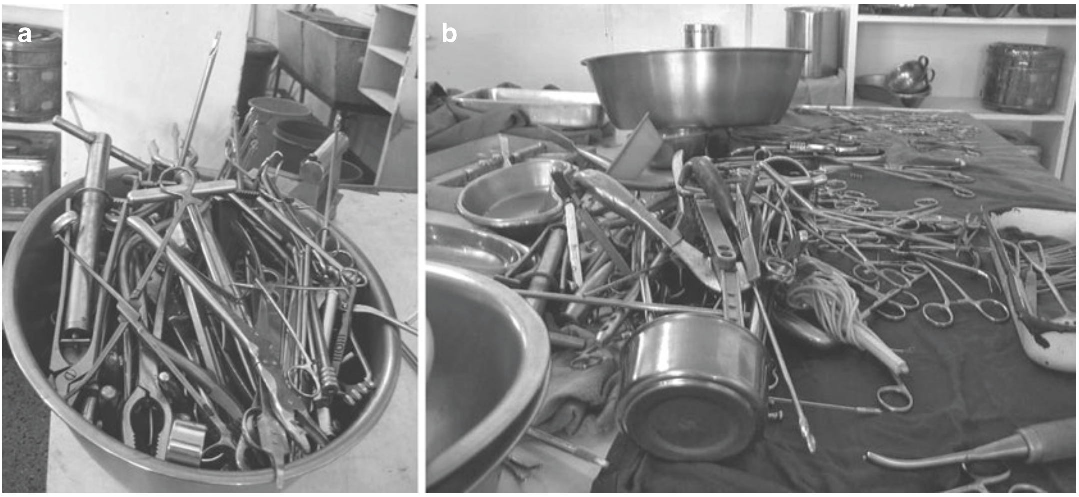

Fig. 7.1 (**a**) Instruments are jumbled together in a pan for washing and (**b**) dumped on the table without regard for preserving the sharp cutting edges or preventing them from bending and breaking

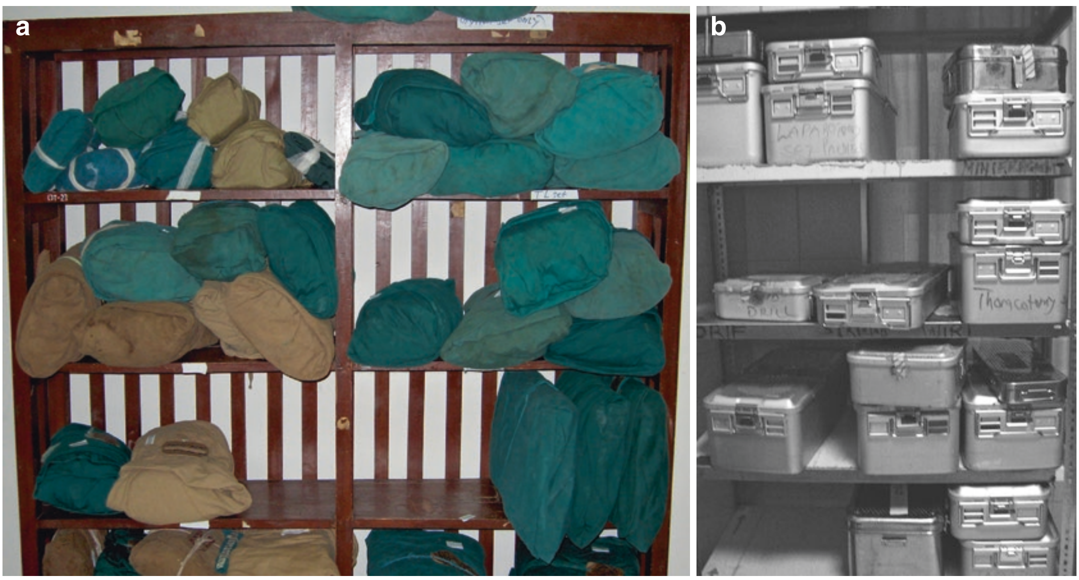

Fig. 7.2 Instrument and implant sets are often wrapped and sterilized in a location remote from the operating room. These sets cannot be inspected without breaking sterility. (**a**) Cloth wrapped (**b**) in somewhat more accessible metal containers

These are some of the problems. This chapter will consider possible solutions including acquisition of local supplies, the ethics of donations, recent initiatives addressing the problem, and sources of purchased supplies.

Local Acquisition

Simple supplies can be arranged from local sources in most countries. Common things like rope and pulleys for traction, plaster of Paris,

Fig. 7.3 Useless and broken equipment becomes a burden

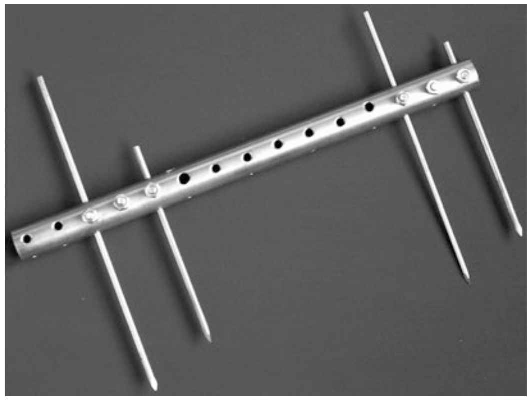

Fig. 7.4 One type of locally made external fixation device copied from the old French Army fixator

razor blades, and common bleach are usually available. Plaster rolls can be made from gauze strips covered with dry plaster of Paris and then rolled up ready for use. Although dangerous, razor blades have been used as scalpel blades. Dakin's solution for dressing changes on open wounds is marketed under that trade name or can be made by diluting common bleach (see Chap. 14 for recipe).

In the past, implants have been made on-site using 316 stainless steels in a local machine shop, but without quality control, this is unsafe for the patient and should not be attempted. The exception is perhaps external fixation devices. While many ex-fix frames are a common donation, informally fashioned frames are a reliable substitute, and some can be reused. Simple solutions include pins and plaster, pins attached to a wooden bar, or more sophisticated metal devices (Fig. 7.4). They will, at least, serve in an emergency to gain fracture stability and wound access.

Centers with functioning prosthetic/orthotic workshops or training schools have access to a range of locally made splints, braces, and artificial limbs. While these vary in quality, a local source is invaluable. Often, physical therapy departments are able to fashion simple splints and braces; however, these will usually be not lightweight devices made from thermoplastic materials. Prepackaged elastic splints with Velcro closure are rarely available or are expensive. Simple wooden crutches made locally function well (Fig. 7.5), though many patients in Africa prefer to use a single, long walking stick, which they use in a poling maneuver and which may be more stable in mud than crutches.

Fig. 7.5 Wooden crutches made at a hospital in Ghana

Prosthetic manufacture requires special training. International Committee of the Red

Cross, Handicap International, the Cambodia Trust, and the International Society for Prosthetics and Orthotics are organizations that conduct training programs throughout the world targeted for developing countries. To be most effective, there should be interaction between patient, surgeon, prosthetist, and physical therapist, making location important, as patients must travel far and remain for the lengthy process of prosthetic manufacture, fitting, and training. There is a great need worldwide for prosthetic expertise.

The Ethics of Donations

Donated orthopedic equipment and supplies are a potentially valuable resource in developing countries. Although it seems as if any donation would be helpful in areas where there is great need, one should look carefully at the cost, sustainability, and ethics before shipping or carrying equipment to an overseas hospital [1].

While the equipment might be obtained for free, the costs involved with shipping, possible customs fees, or added baggage fare could be substantial. Consider whether those funds might have a better use. Much donated material turns out to be unusable once it reaches the country and ends up as a burden rather than a benefit. There are numerous reasons for this such as voltage differences and limited or expired shelf life (Fig. 7.6). Orthopedic donations are often incomplete, having either instruments without implants or vice versa. The following is a list of ethical and sustainability standards that will make a donation more effective:

- Be sure the material being donated is known and agreed upon by the recipient.
- Match the needs of the recipient country with the material being sent. The sets should either be complete in themselves or compatible with existing equipment. Be certain the instruments match the implants.
- The recipient should know how to use the equipment appropriately and safely. If not, include a training period as part of the donation.
- It should be sustainable, by either continued donations or local purchase.
- If it has a shelf life, it should not be outdated. The donated supplies should be as safe to use in the recipient as in the home country.

Fig. 7.6 Two unusable, donated C-arms clutter the limited hall space in a Cambodian hospital. They cannot be fixed or disposed of locally due to the radioactive components

- In general, donations should be made available to all patients regardless of ability to pay.
- The donated material should not interfere with currently available purchased equipment and supplies. It should not compete economically with local markets.[1]

When hospitals switch implants and remodel or equipment manufacturers market a new brand, the unwanted items become a ready source of donated supplies. These typically are given to individuals, sent to overseas programs, or filtered through a host of nongovernmental organizations (NGOs). The NGOs' MedShare and Doc2Doc accept general supplies and equipment for redistribution. Others, such as Remedy and Partners for World Health collect unused, unopened equipment and supplies in prepackaged sets and reassemble them into donor packs. World Access Project collects used wheelchair components, refurbishes them with volunteer help, and supplies them to developing countries. The US section of the International Society for Prosthetics and Orthotics (ISPO) acts as a clearinghouse for new and "gently" used prosthetics and new orthotic products. Along those lines, the NGO Orthopedic Link has been working with orthopedic equipment manufacturers to receive their unwanted equipment sets and match them to specific overseas hospitals, creating a sustainable line of dependable products. Partners for World Health collects equipment and unwanted supplies, repackages them, and then connects with those who need them.

A different approach was developed by SIGN Fracture Care International. This NGO manufactures an FDA-approved, intramedullary, locking nail system that does not require fluoroscopy or a fracture table for insertion. A supply of implants is provided with a training program. As the implants are used, they are replaced without charge if certain details of the cases are provided on an Internet data bank. SIGN also supplies ongoing training through on-site visits and their yearly conference.

[1]For example, if donated rice is given away, it decreases demand and lowers the price for locally grown rice. This decreases production and encourages food dependency instead of developing food independence. A similar concept applies to equipment donations. Free material donations reduce the development of a sustainable local supply system, which is more important than short-term availability. Donations should serve as a foundation for maintenance of the service.

Purchased Equipment

Besides US, European, and Japanese manufacturers, orthopedic equipment is manufactured by firms in India, China, and many middle-income countries. The specific availability is primarily dependent on costs but also on geography. Several of the large US- and European-based corporations have regional offices and manufacturing facilities within reach of Africa and Asia, but their products are expensive for resource-poor hospitals.

A plethora of Indian companies manufacture and distribute orthopedic devices. These are available to countries in the region, and the cost is reported to be lower than similar goods from the USA or Europe. Quality is more difficult to measure, but since 2006, India has a regulatory and licensing process for medical instruments and implants, and many firms provide certification. There seem to be fewer customs problems in some countries neighboring India, making distribution easier. Orthopedic supplies such as plaster, fiberglass, dressing materials, and splints from Indian firms are available in many developing countries and competitive in price.

Indian equipment and supplies are frequently imitated and fraudulently produced by bogus companies to appear as equipment from reputable Indian firms, creating problems due to lower quality. Some items that are considered obsolete in European countries are shipped to Africa at reduced costs. Health administrators are not medical professionals and will therefore opt for cheaper supplies, hence encouraging the flow of these products into the region. These supposed "cheap supplies" might be more expensive in the long term. Medical professionals need to play a more active role in acquiring medical consumables for their facilities to make sure appropriate systems are available.

Conclusion

Solutions include fashioning products from local sources, donated or recycled equipment, and purchased equipment and supplies when funding is available. With all these options, it is imperative to monitor the quality of the product and be certain the providers are trained in its use. In the end, patient safety is most important.

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MedShare. www.medshare.org.
Orthopaedic Link. www.orthopaediclink.org.
Remedy. www.remedyinc.org.
SIGN Fracture Care International. www.signfracturecare.org.
U.S. National Member Society of the International Society for Prosthetics and Orthotics (U.S. ISPO). www.usispo.org.
World Access Project. www.worldaccessproject.org.
https://www.partnersforworldhealth.org/ Recycled medical supplies.

8 Ethics

Michael Krosin

Typically, international work will take place in a setting with different resources from one's home country and in unfamiliar medical and cultural environments. This combination presents ethical considerations one should be aware of prior to embarking and includes patient-centered issues of safety and culture, host country physician issues, host country systems issues, and the special situations of either disaster relief or investigative research.

The foremost priority for any physician is patient safety. Surgery in austere environments that might be standard in one's home country may ultimately create more harm than good. Lack of certain technologies, implants, and a proper sterile environment may create risks that outweigh the benefits. Overly aggressive treatments, which result in poor outcomes, can create lasting mistrust and erode relationships.

There are situations where proper implants and environments exist and difficult procedures may be done safely. However, the aftercare, particularly in the face of complications, may be absent. The availability of aftercare should play a major consideration as to whether a procedure should be performed.

Lastly, proper record keeping should be prioritized by the visiting surgeon. Every effort should be made to establish an accurate, comprehensible, and accessible medical record. While most country's records are paper-based, it is a good idea for the visiting surgeon to keep an electronic file of implants and procedures in the event the paper chart is unrecoverable.

Patient autonomy in decision-making and other cross-cultural issues can present unforeseen challenges. Time, patience, and alternative methods of communication should overcome these barriers. It is important to set realistic expectations and clearly define the risks of a procedure, and in turn, it is helpful to have the patient verbalize his understanding. Patient and family expectations of physician paternalism may lead them to minimize the risks and overestimate the benefits of intervention. Cultural expectations may discourage the patient from asking questions or exercising his right to either decline or discuss treatments. The host country physician may also discourage questions. In certain cultures, other family members may decide on behalf of a patient. It is up to the visiting physician to make sure that a standard of informed consent and dialogue commensurate with the surgeon's own standard is maintained while respecting local culture (Box 8.1).

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Box 8.1 Pointers for Informed Consent

- Prior to talking with the patient, discuss the consent with the translator, and resolve any issues of understanding or translation.
- When possible, use pictures or graphics or electronic devices.
- Describe percentages, odds, and risks using locally accessible analogies. In developing countries, there may be a therapeutic misconception that a foreign doctor will not encounter any problems and everything will be "normal" again.
- Include the patients' family in the consent process if appropriate, but be aware that family members may prevent the patient from asking questions.
- Pause often and allow plenty of time for questions.
- Have the patient repeat back "in their own words" the critical risks, recovery time, immobilization, rehabilitation parameters, and likely deficits of function so that you are sure he understands. Explain that it is important to ask questions and that no question is bad or silly. Let the patient and/or family start by asking questions to get a background understanding even before the consent process begins.

Distinct cultural and societal considerations should be considered prior to therapeutic interventions. For example, cultures that squat and kneel for basic hygiene and in the course of everyday life may preclude certain elective procedures.

In many instances, the visiting surgeon will be partnered with a host country physician. It is likely that conversations comparing different medical systems and standards of care will arise. Talk of "better" methods or standards is liable to foster feelings of inferiority. By describing certain methods as superior, the visiting surgeon can undermine local physician confidence and risk shaming certain members of the medical hierarchy. Always present any method or system as one of many good options.

The visiting surgeon should appreciate rank and seniority and understand that by spotlighting junior physicians, he may be creating problems for them with their superiors at a later date. The visiting surgeon may encounter host country physicians genuinely criticizing the local medical system and standard of care. Voicing agreement may create resentment and at the same time perpetuate further feelings of inadequacy. The visiting surgeon should remain neutral or complimentary regarding the host country's medical care (Box 8.2).

Box 8.2 Ethics: A Case Study

You are a member in a team of visiting volunteer surgeons at a site. This is the first time this site has hosted surgeons, and it is not clear if you will be returning for further volunteer trips. One of the patients you evaluate is a young farmer with a femoral hypertrophic nonunion after closed treatment. He has had the problem for over a year and been unable to work. Your team has appropriate implants and equipment (minus a c-arm) to treat the nonunion, but the infection rate for internal fixation at this site is 10%. The junior local surgeon has experience with intramedullary nails and would like to proceed with the case with you as an assistant. The senior local orthopedic surgeon is willing to proceed with the case, but you sense he is somewhat tentative.

Considerations to think about:

- Patient safety and risk vs. benefit
- Technical and technological capability of follow-up and management of infection
- Patient informed consent
- Respect for local seniority

Resolution 1: Following a lengthy discussion in private with the senior orthopedist, you learn that in the past, he has had some very poor outcomes with infected femoral nonunions and feels uncomfortable in their management but did not want to voice this. Following a discussion, he is willing to go along with fixation if there is a plan in place in case of infection. You discuss the plan with the senior surgeon first and then with both local surgeons to do a nail removal and washout in the case of infection and leave the patient hopefully no worse off. You also will leave a larger diameter nail if a washout and repeat nailing are needed. They have appropriate hand reamers. A thorough informed consent with the patient occurs with translator, both local surgeons, and visiting surgeon present. The likelihood of a complication is expressed in terms the patient understands, and his comprehension of this is verified to a degree you feel confident in his understanding. He agrees to proceed with the surgery.

One should be aware of issues regarding favoritism for members of certain religions, political parties, and ethnicities. The visiting surgeon should make every effort to encourage a fair and equitable distribution of resources. The host country may have become reliant on visiting medical personnel and equipment, and while this is understandable in the setting of scarce resources, it can also stifle the development of a sustainable local health delivery system. The visiting surgeon can help the host country's physicians advocate for greater resources by encouraging data collection. This can later be used to justify additional investments.

Involvement of residents in an orthopedic global outreach requires a well thought-out framework of ethics (Box 8.3).

International research and disaster relief introduce a complex set of ethical considerations. International research subjects are most often considered vulnerable populations, and it is mandatory to adhere to the basic principles of respect, justice, and beneficence as outlined in the Belmont Report on human subjects research [1].

Box 8.3 Moving from Service and Mission to Collaboration and Empowerment

The orthopedic profession has a long history of volunteerism and humanitarian pursuit. Organizations such as Orthopedics Overseas (OO), Operation Rainbow, and Operation Walk have a substantial history of global outreach activity.

Orthopedic surgeons, by their inherent skills, have the ability to achieve dramatic change in individuals' lives: from disability to functional recovery and gainful employment. It is therefore not surprising that the immediate concept of global outreach to the lay public as well as the orthopedic community is the performance of surgical procedures, be they through surgical mission trips or disaster relief.

With increasing global activity, a growing concern has emerged during the last decade of the importance of sustainability and awareness of untoward negative aspects of these efforts. The emergence of a new "medical colonialism" has been described and discussed in academic and public health journals, showing that well-intentioned orthopedic interventions can weaken health systems and disempower the people we wish to help.

After a decade of mission trips with Operation Rainbow in the 1990s, the residency program at the University of California, San Francisco (UCSF), became increasingly aware of the limitations of this outreach approach. In response, UCSF partnered with Orthopedics Overseas to expand the residents' exposure to the problems encountered in austere settings by creating a global orthopedic elective at the OO site in Mthatha, South Africa. The concepts of teaching, training, appropriate technology, and sustainable empowerment were embraced as the enlightened approach to volunteerism.

From Hippocrates work, *Of the Epidemics*, the concept of *primum non*

> *nocere*—first, do no harm—has been an essential concept engrained in every medical student's lexicon. Throughout surgical residency, reminders of this premise are constantly given from the "gray hairs" in the back of the room. As we venture with enthusiasm toward orthopedic outreach and humanitarian relief, the same scrutiny should be applied. Orthopedic surgeons can be a powerful force for change, not just on the individual level but on the population level through their involvement as witnesses and storytellers, advocating for global equity of musculoskeletal care. Surgical outreach through knowledge transfer, advocacy, and empowerment of our surgeon colleagues is the sustainable approach.
>
> *—R. Richard Coughlin, MD, MSc.*

During disaster relief, resource distribution, patient triage, and the appropriateness of certain procedures should be considered in the greater context of the disaster. The lack of infrastructure and support may make certain types of volunteer relief work inappropriate and a detrimental strain on scarce resources. International work in these situations should be undertaken only with a coordinated and experienced team.

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9 Culture Shock and Traditional Healing

Michelle Foltz and Geoffrey Walker

Culture Shock

There is no guaranteed way to prepare completely for cross-cultural encounters. Talking with people who have had similar experiences often builds the excitement that accompanies such journeys, but what others felt and how they dealt with problems will seldom match what one finds on arrival. Reading about the politics and current events and exploring the local literature provide a perspective, but sometimes, the perspective is wide of the reality on the ground. Though every volunteer develops an individual approach to deal with each situation, common threads to successful adaptation include a willingness to communicate, a genuine receptivity to new ideas, and a ready sense of humor—all coupled with a healthy dose of humility.

The initial shock may come from the bombardment to all senses by unfamiliar levels of poverty, hygiene, and sanitation. People impinge on one's space, shout, push and shove, or bow their heads and whisper without making eye contact. Their answers to questions may not make sense, and the response to a friendly greeting and "thank you" can be a quizzical stare. Arriving ill or fatigued magnifies the sense of strangeness.

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The concept of culture shock was formalized in the 1950s and has proved to be a common and predictable evolution of variably timed stages that a person goes through when first arriving in an alien culture. The initial fascination with one's new surroundings gives way to more unpleasant feelings, associated with heightened anxiety as the differences are brought into sharper contrast. In the next stage, one finds ways to adjust and eventually reaches a balanced modus vivendi [1].

For orthopedic surgeons, the adjustment to working in an austere setting, with all the manifestations of life lived close to survival mode, is further complicated by professional culture shock. All diseases have a social component, but in the face of limited resources, the complications and variables due to those social components carry added weight (Fig. 9.1). Patients present late and may not follow instructions for a 100 reasons. They take risks we do not understand and show a fatalism that is both admirable and self-defeating (Fig. 9.2). Their histories do not follow a time frame or idea of cause and effect we assume to be universal (Fig. 9.3). They do not return for follow-up as appointed but show up a month late with smiles and a destroyed cast barely covering an infected surgical wound. They do not always tell what we consider the truth—reality is sorted out differently when one lives on a dollar a day. The limitations within the local system seem endless and unexpected—no beds,

Fig. 9.1 Patients arrive at the hospital or clinic by many different means. (**a**) This patient was picked up on an unlit street after being run over in Kabul. His leg was splinted with available materials; he was thrown into the back of a bystander's pickup and brought to the hospital. There are no EMT services in many countries. (**b**) Families carry their injured or ill. (**c**) They use whatever is available, such as a wheelbarrow. (**d**) The buffalo ambulance must stop to eat and rest on the way to the clinic

repeatedly cancelled operating time, lack of dressing gauzes, and no anesthesia meds or absent anesthetist. The brand-new hospital constructed with aid money is already falling apart; the hospital has instruments to treat spinal fractures but no soap. Time is fluid and drags due to inexplicable delays. Learning to cope with such dissonance can be frustrating, but it can also be the most interesting aspect of volunteering in austere environments. At all levels, the local doctors know the limits; follow their advice.

Traditional Healers

The practices of traditional healers, bonesetters, and witch doctors, and the beliefs that make them a major contributor to medical care globally, are

Fig. 9.2 Unsafe and frankly bizarre forms of transportation are immediately evident on arrival in many low- and middle-income countries. (**a**) Overcrowded, (**b**) unconventional use of space, and (**c**) dangerous equipment. The long handlebars on this *kolyn* make it difficult to turn (**d**) passenger ignorant of the dangers

very much a part of orthopedics in the developing world. Hospital-based surgeons see the mishaps of traditional bonesetters in the form of malunions and nonunion of fractures and at its most extreme, bonesetter's gangrene (Fig. 9.4). They also see their own patients leave the hospital to be treated by traditional methods. It is important to realize that the majority of orthopedic patients seeking traditional care unite their fractures and heal their injuries, though maybe not as well as we think we could have done (Fig. 9.5). People patronize traditional bonesetters because they are local and readily available, are less expensive than care in a government or private hospital, and are known and trusted entities that satisfy the patient's and the patient's family's cultural beliefs. Fear of amputation is another reason people seek care from traditional healers instead of hospitals [2].

Bonesetters' methods are similar in many different settings and rely on immobilization with or without manipulation, achieved with a splint of bamboo or wood, which is applied tightly to the extremity with cloth or rope. Traditional bonesetters don't often recognize the damage caused by tight splints or how to deal with

Fig. 9.3 This mentally disturbed West African woman was sure her external fixator was the source of the "bad medicine" that was preventing her fracture from healing, and she took the situation into her own hands

increasing pain after their application (Fig. 9.6). Herbs, powders, or unguents that irritate and blister the skin may be used as a dressing under the splints (Fig. 9.7), and heat is a common element in traditional treatments. Recognizing the cultural barriers, some enterprising surgeons have lowered amputation rates with short courses aimed to educate and share ideas with traditional bonesetters [3].

Some traditional methods such as scarification, rubbing metal on the skin to induce inflammation, or cupping are common throughout the world in dealing with aches or pain (Fig. 9.8). Local plants or ash from plants is often used in conjunction with these physical modalities. Some patients try to hide that they first sought consultation from a traditional healer; others are open and freely discuss the efficacy of the treatment.

Traditional medicines—like all treatment modalities—rely on the faith that both the patient and healer bring to the situation. It is normal to be sickened at the sight of a child's dead arm because of a bandage applied too tightly and for too long, but there are many treatments that do little harm. Think of Western patients who increasingly use the unproven remedies that make alternative medicine a multibillion dollar business. Remain open. We are there to help, not to judge.

Reverse Culture Shock

Preparing for culture shock on return to one's home might seem nonsensical, but volunteers often talk about the unexpected disorientation and irritation that overtakes their homecoming—reverse culture shock. The adrenaline that made the foreign situation uniquely immediate is no longer present. The few weeks of learning to work within limitations and finding solutions have been lived fully and much was learned. Few friends or colleagues at home will understand the experience or how and why it left such an indelible impression. The old life seems dull and superficial, maybe too easy. A similar adjustment of attitudes and acceptance that allowed one to work in an austere environment will smooth the way home and in turn prepare one for the next volunteer opportunity.

Fig. 9.4 (**a**) This young Sierra Leonean man had been treated by a tradition healer for a couple of months before he arrived in an NGO hospital septic, anorexic, and malnourished with pus draining from his axillary lymph nodes and a mummified hand and forearm. (**b**) His arm unwrapped in the operating room. The surgeon performed an open shoulder disarticulation with delayed primary closure 1 week later. (**c**) Patient a few months later

Fig. 9.5 An Afghan traditional bonesetter made this comfortable and purposeful splint for a closed tibia fracture

Fig. 9.6 The devastating results of a splint applied too tightly

Fig. 9.7 Medicinal leaves wrapped around a fractured humerus were uncovered when the bamboo "Chinese splint" was removed

Fig. 9.8 The discolored cupping welts on the back of a Cambodian surgical trainee after he sought care from a traditional healer for nonspecific complaints of malaise

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Part II

General Clinical Topics

10 Coexisting Medical Conditions

Michelle Foltz and Richard A. Gosselin

Chronic Diseases or Illnesses

The self-reinforcing constellation of the chronic noncommunicable diseases and conditions – diabetes, obesity, hypertension, and respiratory and cardiac disease – that adversely affect the management of orthopedic conditions in high-resource countries present more varied and complex problems in the developing world. Besides occurring at a younger age and being poorly controlled, patients may not be aware of the extent of their medical problems, may fail to understand the need for long-term medication to control the pathology, or may not have the resources to buy necessary drugs. The expensive tests, therapies, and consulting expertise found in Western health systems to prepare patients for elective surgery are lacking in resource-poor settings. Managing trauma in the face of unaddressed and unmanaged comorbidities can transform already complicated situations into complex life-threatening ones [1, 2].

Western diet, a sedentary urban lifestyle, and increasing longevity due to improvements in public health contribute to the ongoing increase in cardiac disease. The greater availability of antibiotics, even when inappropriately used, has seen a decrease in rheumatic heart disease, but it still remains a relatively common medical problem in developing countries, especially among the young and young adult populations. Unrecognized diminution in cardiac reserve and the lack of drugs outside the basics can compromise anesthesia and recovery.

Seventy percent of the over 280 million people with diabetes live in low- and middle-income countries (LMICs). It is one of the fastest growing chronic diseases, both in incidence and prevalence. The majority is type II diabetes, often undiagnosed for years leading to the additional burden of diabetic retinopathy, renal disease, and neuropathy that compromise orthopedic outcomes [3].

The world's burden of chronic respiratory disease falls disproportionately among the poor in developing countries. Households that depend on open fires for food preparation often have poor ventilation, or the fuel incompletely combusts, causing high levels of chronic indoor particulate and toxic chemical pollution. Growing levels of air pollution in urban areas – caused by an increase in motorized transport, traffic jams of idling cars, spewing fumes from poorly tuned vehicles, and using inadequately processed petrol – increase the amount of low-grade, unaddressed chronic pulmonary pathology that can increase postoperative complications [4].

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Ophthalmologic disease is widespread in developing countries and is often unrecognized or untreated. Trachoma, a highly contagious Chlamydia infection scarring the eyelids, cornea, and conjunctiva, is endemic in many parts of the developing world and, like most infectious diseases, is associated with poor sanitation and hygiene and disproportionately affects the poor. With an increase in both life span and the incidence of diabetes, untreated cataracts are a common cause of blindness or poor vision. Many public health systems lack formal visual screening programs.

Many public health workers consider tobacco as the number one health problem in the developing world. Its association with the increased incidence of cardiac and respiratory diseases and diabetes makes it a particularly lethal problem. Few smokers in developing countries fully understand the deleterious health effects of tobacco. Governments have little money or incentives for education campaigns and "Big Tobacco" actively lobbies to limit anti-smoking legislation or proposed tax increases that could potentially curb tobacco use. The idea that smoking adversely affects a wide range of health issues, including fracture healing, is laughable to many smokers in developing countries [5].

Nutrition

Malnutrition is difficult to assess clinically. Even in families with apparently well-nourished or frankly obese individuals, some members, especially women and children, may have unrecognized severe malnutrition. The deficiencies can be in calories, protein, vitamins, micronutrients, or any combination. Few developing country laboratories are equipped to sort out the specific deficiencies, while supplements may be beyond the means of the system and the individuals. Economic development, particularly in middle-income countries, is leading to a fairly new form of malnutrition: overnutrition. The prevalence of obesity is rapidly increasing in both sexes and in all age groups [6]. Adverse effects on health in general and orthopedic conditions in particular are well known.

Eating is highly cultural with certain food combinations prohibited or prescribed for the sick and ill that may not conform with a Western-trained physician's idea of proper nutrition. High-protein meals are recommended for trauma and burn patients and those with catabolic complications. Multiple trauma patients can require up to 6000 cal/day. Families should be encouraged to provide supplemental proteins and calories in the form of eggs, milk products, meat, and legumes.

Deficiencies in vitamin D and calcium leading to osteoporosis and osteomalacia are common in women, including young women, living in societies that demand all parts of the body be covered. Osteoporosis is further compounded in the same populations by restrictions of physical activity. The lack of safe streets and areas for exercise further enforces a sedentary lifestyle among the growing middle class. Walking for exercise and enjoyment appears to many who have recently purchased a car to be a step backward in personal economic development. Supplemental calcium, vitamin D3, and vitamin C in sufficient and bioavailable doses may improve fracture healing and, if available, should be encouraged (Rickets is discussed in Chap. 12).

Some areas have a high incidence of iodine-deficiency goiter, though most such individuals are euthyroid. In severe cases, hypothyroidism may develop and complicate orthopedic treatment.

Anemia and Hemoglobinopathies

Chronic anemia is a widespread problem in developing countries, especially in women following multiple pregnancies and in children after repeated bouts of malaria. A hemoglobin (Hb) level below 6 g compromises the body's ability to heal acute injuries, infections, and chronic conditions. Such patients require blood transfusions before even minor surgery, such as skin graft. Some surgeons will not do skin grafting if the Hb is below 10 g [7], but more important than the Hb value is the quality of the granulation tissue, itself dependent on good tissue oxygenation. We would not hesitate to skin graft on a good granulation bed with an Hb of 8 g. Organized blood banks may not be present or reliable, making family members a common source of transfused blood, often with only rudimentary cross matching. Local doctors are usually adept at "conjunctiva grams" – correlating the color of the conjunctiva of the lower eyelid with an Hb estimate or observing the color of the tongue or palm – but a fingerstick Hb is more reliable.

Though hardly a disease, pregnancy as a "comorbidity" needs to be assessed in young women. The attendant anemia, potential hypertension, and cultural restrictions may complicate orthopedic treatments. It is wise to assume that all women of childbearing age are pregnant and ask a colleague how best to verify this.

Hereditary coagulopathies, such as hemophilia A or B, are severe diseases and not commonly seen in low-income countries, because of the short life expectancy. In middle-income countries, the diagnostic and therapeutic resources may be available for treatment, and one might see a child or adolescent with a musculoskeletal complication, such as a chronic arthropathy, with stiffness or ankylosis. Any procedure, including closed manipulation, is at high risk for complications and should be considered only if hematology expertise is present and replacement factors are available in adequate supply. Milder forms of coagulopathies are often undiagnosed and may present as significant postoperative bleeding [8].

Hereditary hemoglobinopathies such as sickle cell disease or thalassemia are common in LMICs. They are recessive diseases. The heterozygotes are healthy carriers of the trait, which is said to be protective against certain diseases such as malaria. The many forms of thalassemia are seen in Asia, the Middle East, and some parts of Africa. They are relevant to orthopedic care only because they are associated with chronic anemia. Sickle cell disease on the other hand has significant, sometimes dramatic musculoskeletal manifestations. It is common in West Africa and to a lesser degree around the Mediterranean basin. It should be part of the routine differential diagnosis for musculoskeletal pain and/or infection.

Sickle cell crisis manifests with acute abdominal and/or long bone pain, which can be multifocal and severe. Both proximal humerus and femur and vertebrae are common sites, leading to avascular necrosis with degenerative joint disease or acute and subsequent chronic osteomyelitis, usually with a visible sequestrum on x-ray. The differential diagnosis between a sickle crisis and acute osteomyelitis is not easy, especially in children. In general, acute osteomyelitis will give a slightly higher fever and a more elevated white count. Older patients who have had crises before can usually say if their symptoms are the same or different compared to previous episodes.

The cornerstones of treatment are transfusion for anemia and aggressive PO or IV hydration. If there is no significant improvement at 24 h, empirical use of antibiotics should be considered. X-ray changes are late findings, and the decision to decompress a suspected infection should be based on other factors (see Chap. 29).

Sequestrectomy, after correction of the anemia, is the treatment of choice for chronic osteomyelitis in association with sickle cell disease. We have found no evidence in the literature to support the idea that use of a tourniquet will precipitate a crisis [9]. We have undoubtedly and unknowingly performed many procedures on sicklers using a tourniquet without obvious deleterious effects. The benefits of a clear and dry field outweigh the risks, if any, in our opinion (see Chap 31).

Infectious and Parasitic Diseases

High incidences of hepatitis A, B, and C are found in many developing countries leading to acute and chronic liver disease that may impinge on healing orthopedic injuries and infections. Poor sanitation and lack of controls regarding food processing lead to hepatitis A. A history of widespread, poorly controlled past public health policies that allowed programs to reuse unsterilized needles for vaccinations and injections has spread hepatitis B and C.

The patterns of incidence for HIV/AIDs (see Chap. 15), the hepatitises, and TB (see Chap. 33) vary among countries and even within the regions of a country. One's local colleagues should be able to give an idea of prevalence and specific signs and symptoms to help make these diagnoses.

Over half a billion of the world's people are infected with malaria. The plasmodium species account for between one and two million deaths per year, primarily in children under 5 years. The stress of trauma and/or surgery may set off a recurrence of the chronic illness. Patients who have had previous episodes will often self-diagnose their condition. Malaria should be considered in the differential for any fever in endemic areas, but it is mandatory that postoperative wound infection be ruled out as a cause of fever even while treating the parasite. As with TB, the diagnosis of malaria requires some human and laboratory resources that are not always available. The tests yield a fair number of false negatives, and it is common for local providers to start malaria treatment without a confirmed diagnosis. A rapid clinical improvement is a reliable sign that the diagnosis is correct.

Parasitic helminths are widespread and highly correlated with poverty, poor community sanitation, and ignorance of hygiene. 1.3 billion people worldwide have ascaris infestation [10]. Even moderate infections in children can lead to undernutrition. Over 20,000 people per annum, primarily children, die of such infestations, usually due to bowel or biliary obstruction. The prevalence of hookworm stands at one billion and is a common cause of anemia due to chronic blood loss from the intestine [9]. These and other roundworm infestations are treated with a short course of albendazole or mebendazole. In highly endemic areas, routine treatment on admission may be warranted.

The blood fluke causing schistosomiasis is endemic in the bodies of still freshwater of many tropical and subtropical developing countries. Two hundred million people worldwide are infected with over 20 million having chronic illness due to persistent infection or irreversible damage to the GI and GU systems [9]. A large proportion of those infected are aged 14 and under. It is rated the second most important socio-economic/public health problem after malaria and can compromise orthopedic treatment.

Other Comorbidities

Alcohol and mind-altering drugs are a growing problem in LMICs, because of an increase in disposable income. Alcohol is known to interfere with fracture healing, and cocaine is well known to cause anesthetic complications. The local substance of preference may be one that is unfamiliar to a visiting surgeon, producing a confusing constellation of signs and behaviors, especially in the face of shock and trauma. The local emergency room or outpatient department personnel will usually have experience with specific local products and are the best source of information. Substance abuse is highly associated with both non-intentional injuries, such as road traffic injuries, and intentional injuries caused by violence. It is estimated that worldwide around 15% of the burden of trauma is alcohol related, even higher in certain areas [11]. Complications of chronic alcoholism, such as clotting disorders or withdrawals, should be kept in mind when preparing for surgery.

In some populations, gout is a significant problem leading to severe disability. Tophi in unusual areas and inflammation masquerading as soft tissue infection or osteomyelitis can make diagnosis difficult, especially during a perioperative flare-up.

Though diabetes is rapidly becoming the world's leading cause of peripheral neuropathy, in tropical and subtropical areas where leprosy is common, it is still a significant source of hand and foot deformity due to motor loss and imbalance and sensory loss (see Chap. 11).

Some populations are predisposed to dental caries due to the mineral composition of their teeth or the limitations of diet, which when combined with poor oral hygiene can lead to severe periodontal infections which may seed operative or injury sites. Loss of teeth or loose teeth interferes with adequate nutrition. Although outside the realm of orthopedics, tooth abscess may lead to maxillary or mandible osteomyelitis.

Basic knowledge of tooth extraction and drainage of facial bone infections can come in handy in areas where resources are limited.

Populations in developing countries are not immune to depression. According to the World Health Organization, major unipolar depression is a significant contributor to the global burden of ill-health. Dealing with a limb- or life-threatening orthopedic disease or injury is stressful even though patients may not display depression in ways Western surgeons are used to. Local health staff can identify such patients and help provide culturally sensitive care and counseling. Victims of conflict present a very wide spectrum of orthopedic injuries and conditions but share in common a high prevalence of psychological scarring, such as post-traumatic stress disorder (PTSD) [12]. This aspect of patient management cannot be overlooked and may have a significant negative effect on the overall outcome (see Chap. 44).

Many patients will not be aware of having comorbidities that can complicate their orthopedic management or know that past illnesses have left residual health problems. Besides the chronic systemic impairments common in high-resource medical practice, many of the comorbidities are tropical diseases for which most volunteers will have little experience. Many of these conditions have characteristic clinical presentations, making it especially important to complete a thorough exam, including a diligent dermatological inspection. Diseases such as leishmaniasis, Chagas disease, hydatid disease, typhoid fever, and amebiasis may be common in limited areas. Ask the local doctors what coexisting morbidities they typically encounter, the clinical presentations, and how they are best treated.

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11 Tropical Diseases and Orthopedics

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Introduction

Some musculoskeletal diseases and conditions are seen almost exclusively in tropical environments. This is due to the tropical climate but also to associated conditions such as poverty, malnutrition, or overcrowding [1, 2]. Although "tropical medicine" is often considered synonymous with "tropical infection," a broader scope includes all ill effects on health from exposure to a tropical environment. The majority of western surgeons will have had little exposure to most of these conditions during their training.

As with other conditions discussed in this book, most patients will present in advanced stages of disease, and diagnostic resources will be limited. Local surgeons and other providers are usually knowledgeable about conditions endemic to their area, and seeking their input in the diagnosis and management is crucial. The following is a brief overview of orthopedically relevant tropical diseases and conditions one might encounter. They will vary across geographic areas, sometimes even according to seasons.

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Bacterial Infections

The bacteria that commonly cause bone, joint, and soft tissue infections are the same all over the world for the same age groups; however, volunteers might encounter unfamiliar presentations of familiar infections and infections caused by unusual organisms.

In many places, cultures and sensitivity, even Gram stains, are unavailable or unreliable or may take such a long time to obtain that they serve little use. Antibiotic therapy is often dictated as much by what is available as what is efficient and often started empirically [3]. Although newer antibiotics such as the quinolones are available worldwide, in many places older antibiotics such as chloramphenicol, cloxacillin, and ampicillin, which are not widely used in high-resource settings, are still commonly employed. Hospitals have oversight on the quality of antibiotics they purchase, but outside "pharmacies" often provide cheaper medications of indeterminate quality. One must assume that most patients will not be fully compliant, stopping their medication as soon as they feel better and keeping the rest for later, making it not uncommon for a patient to return to

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the outpatient clinic who is not "responding" to treatment.

Gas Gangrene

Gas gangrene most commonly results from a wound infected by C*lostridium perfringens*, a Gram-positive anaerobic bacillus, but also, on occasion, from some group A streptococci (so-called flesh-eating disease) or *Staphylococcus aureus* (Fournier's perineal gangrene). A high index of suspicion is necessary for the rare patient seen in the early stages of a foul-smelling, crepitating wound, when aggressive surgical debridement might still be limb or lifesaving. Whether the underlying pathology is a necrotizing myositis, fasciitis, or dermatitis is clinically irrelevant. They all need surgery and high doses of penicillin, combined with clindamycin if available. Ironically, penicillin is becoming more difficult to find as worldwide production has drastically decreased. Cloxacillin, amoxicillin, and combinations such as augmentin (amoxicillin and clavulanate) are more readily available. Metronidazole, chloramphenicol, and rifampin are acceptable second choices. Most patients present late, with severe systemic manifestations, extensive limb involvement, and only a proximal amputation or disarticulation may be lifesaving (Fig. 11.1). If the infection reaches the trunk, only palliative measures are indicated (Fig. 11.2).

Tetanus

Tetanus is not a surgical condition per se, but it is surprisingly common in many parts of Africa, and a volunteer may have to help with the medical management. Inoculation of the spores of *Clostridium tetani*, another Gram-positive anaerobic bacillus, in a wound causes the release of the neurotoxin tetanospasmin. The adult form of tetanus occurs after contamination of a traumatic wound, and the neonatal form comes from indigenous umbilical cord dressings made with mud or dung. In the adult, the disease appears after a 1–3-week incubation period. Some of the first signs are trismus or lockjaw, severe spasms of a limb, or unaccountable contracture of a joint, which should alert the clinician to the underlying diagnosis. This progresses rapidly to more generalized contractions (tetani) and systemic involvement with mortality around 30% if untreated (Table 11.1).

In the newborn, incubation is 3–7 days. Generalized contractions appear after a period of irritability and inability to suckle. Mortality is above 70% if untreated [4]. Treatment for both forms of tetanus requires nonspecific supportive measures, including a dark and quiet environment, antibiotic therapy with metronidazole and penicillin, surgical debridement if the patient's condition permits, and sedation with benzodiazepines. If available, human immunoglobulin should be used; antitoxin is controversial in the neonatal form.

Brucellosis

Brucellosis, caused by aerobic Gram-negative coccobacilli, occurs from contact with animal parts or ingestion of unpasteurized dairy products. One of the disease's most common manifestations is a monoarticular, chronic, indolent arthralgia, with occasional bouts of severe acute pain. It also mimics spinal TB both clinically and radiographically. Treatment is with streptomycin and doxycycline.

Ulcers

Ulcers are annoyingly common in tropical environments [5]. Both *tropical* (*phagedenic*) *ulcers and Buruli ulcers* (see next section) are manifestations of infections. Tropical ulcers are seen almost only in adults and occur below the knee [6] (Fig. 11.3). They start frequently after an innocuous injury with a painful indurated patch of skin that becomes a pustule over 5–10 days. When this bursts, a full thickness round or oval ulcer is visible. This grows for 4–6 weeks, at which time, the pain subsides. The borders are regular, without undermining.

The ulcer will either heal on its own over the next weeks to months or become chronic, typically showing a poorly vascularized bed and secondary infection. Late underlying osteomyelitis or carcinomatous degeneration is common. The most common infecting microbe is

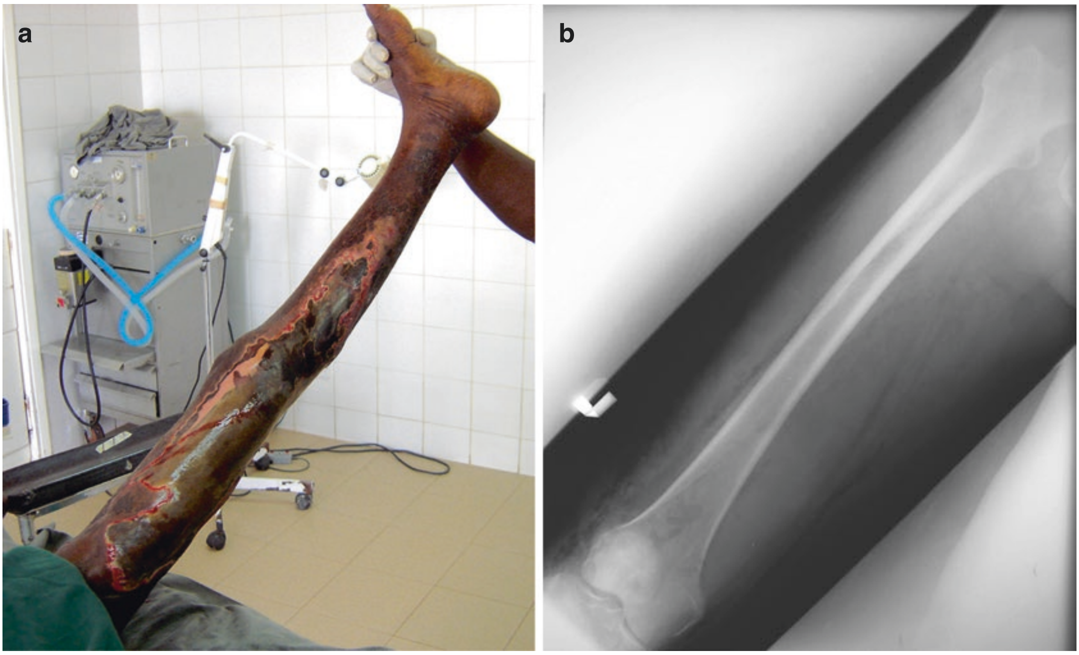

Fig. 11.1 (**a**) Gas gangrene involving the entire lower extremity of the young male patient who died of sepsis shortly after hip disarticulation. (**b**) X-rays show gas in the soft tissues and dissecting between muscle planes

Fig. 11.2 Extensive gas gangrene of the entire left upper extremity of an elderly woman, with visible typical copper discoloration of the skin extending to the supraclavicular area. Even a forequarter amputation would not have saved her life

Bacillus fusiformis, but spirochetes are also found. Antibiotics are helpful in the acute phase (penicillin, erythromycin, fluoroquinolones), or to manage secondary infections, but proper wound care using daily nonadherent dressing and sharp removal of necrotic tissue is the cornerstone of treatment. Attention to the patient's nutritional status and treatment of anemia are important adjuncts. Long-standing ulcers require surgical debridement, often more than once, and split-thickness skin grafting, if and when the bed is adequate. The debridement does not need to be aggressive at the edges as there is little undermining. Many patients live for years

Table 11.1 Management of tetanus-prone wounds

Types of wounds likely to favor the growth of tetanus organisms include				
Compound fractures				
Deep penetrating wounds				
Wounds containing foreign bodies (especially wood splinters)				
Wounds complicated by pyogenic infections				
Wounds with extensive tissue damage (e.g., contusions or burns)				
Any wound obviously contaminated with soil, dust, or horse manure (especially if topical disinfection is delayed more than 4 h)				
Reimplantation of an avulsed tooth is also a tetanus-prone event, as minimal washing and cleaning of the tooth is conducted to increase the likelihood of successful reimplantation				
Wounds must be cleaned, disinfected, and, if appropriate, treated surgically				
History of tetanus vaccination		Type of wound	Tetanus vaccine booster	Tetanus immunoglobulin
Three or more doses	<5 years since last dose	All wounds	No	No
	5–10 years since last dose	Clean minor wounds	No	No
		All other wounds	Yes	No
	>10 years since last dose	All wounds	Yes	No
<Three doses or uncertain		Clean minor wounds	Yes	No
		All other wounds	Yes	Yes

Fig. 11.3 Typical location and appearance of a tropical (phagedenic) ulcer. Note: the edges are not elevated, and the granulation tissue is of poor quality

with an ulcer, as it is painless and does not affect function. The chronic foul-smelling drainage is a common reason for consultation; by which time, chronic osteomyelitis or squamous cell carcinoma is common and amputation the only option.

Mycobacteria

Bone and joint tuberculosis is addressed in Chap. 33. The other common mycobacterial diseases are *Buruli ulcer* and *leprosy*.

Buruli Ulcer

Buruli ulcer is caused by *Mycobacterium ulcerans* (Fig. 11.4). It affects all ages and any body part in children, but primarily the extremities in adults [4, 7, 8]. It usually starts as a painless nodule that progresses rapidly to a painless ulceration. The edges of the ulcer are irregular and always show some undermining, which is often extensive. The skin margins are indurated and the ulcer can progress to involve a significant portion of the limb or trunk. It eventually reaches below the deep fascia and can involve the muscle, tendon, and even bone. Significant deformities and contractures affecting function are common. The earlier treatment is started the more successful it is, making a high index of suspicion important. The WHO recommends 6–8 weeks of rifampin and streptomycin, but surgery is often necessary. The debridement needs to be aggressive, the margins widely excised through healthy skin—at least a couple centimeters beyond the undermining—and the wound later skin grafted. An overly conservative excision almost guarantees a recurrence, with loss of the skin graft. Overall, the results of treating Buruli ulcers are much better than those for tropical ulcers.

Fig. 11.4 Typical location and appearance of a Buruli ulcer, with elevated edges and centrifugal skin changes

Leprosy

Leprosy is caused by *Mycobacterium leprae* and, although in overall decline, is surprisingly common in poor countries, with around 250,000 new cases/year. Historically, and to this date, it carries a high stigma [9]. It is less contagious than TB, but like TB, it is a disease of poverty. Overcrowding, malnutrition, chronic diseases affecting the immune system, and illiteracy are all risk factors. The chronic inflammatory response affects primarily the skin, eyes, and peripheral nerves.

Although infectious in nature, the disease behaves like a chronic, progressive peripheral neuropathy affecting both sensory and motor nerves [10]. Loss of proprioception and temperature sensation combine to create chronic wounds of the hands and feet that lead to secondary infection, necrosis, and, in the late stages, amputations. Progressive loss of motor function, particularly in ulnar and median nerves, creates deformities and contractures of the hand (Fig. 11.5). Medical treatment with a combination of rifampicin, clofazimine, and dapsone is highly effective, but many patients present late, with irreversible musculoskeletal sequelae. Surgery can benefit selected patients under medical treatment: nerve transposition or decompression, tendon transfers, or even arthrodeses. Malignant degeneration of chronic lesions most often requires disarticulation at the level of the proximal joint.

Fungi

Deep soft tissue involvement can be seen with almost all fungal infections, but unless the patient is immunocompromised, bone and joint involvement is rare [11]. Histoplasmosis, candidosis, aspergillosis, cryptococcosis, and coccidioidomycosis should be part of the differential diagnosis of bone infections in HIV-positive patients. The more common fungi that affect musculoskeletal structures are as follows.

Fig. 11.5 Moderately advanced lepromatous involvement of the ulnar three fingers, with classic dystrophic "tapering". (Courtesy of Dr. Sam Baker)

Blastomycosis

Blastomyces dermatitidis can present as multifocal soft tissue abscesses and chronic osteomyelitis (Fig. 11.6). Oral itraconazole is the recommended treatment, with surgical drainage if necessary.

Mycetoma or Madura Foot

Mycetoma or Madura foot (Fig. 11.7) is a chronic soft tissue infection of the feet, usually seen in male farm workers, most often following a penetrating injury, which culminates in chronic osteomyelitis. Mycetomas are caused by actinomycetes bacteria (actinomycetomas) or fungi (eumyceto-

Fig. 11.6 (**a**) Craniofacial deformity and ulceration of left arm in child with blastomycosis. (**b**) X-ray of the skull shows no involvement of the frontal bones. (**c**, **d**) Clinical and X-ray appearance of chronically ulcerated and fungating lesion secondary to underlying chronic blastomycosis osteomyelitis

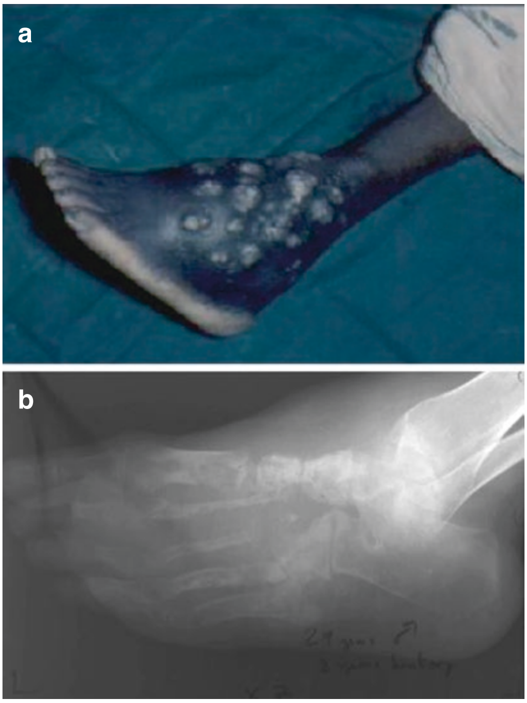

Fig. 11.7 (**a**) Typical appearance of a foot and ankle chronically infected with mycetomas (Madura foot), with multiple draining sinuses. (**b**) X-ray shows advanced destruction of the entire bony architecture of the foot

mas). They are endemic in Africa, the Indian subcontinent, Central America, and northern South America. Lesions can be present for many years. Depending on the severity of the disease and the amount of bone involvement, treatment includes oral itraconazole, surgical debridement, or BKA.

Parasites

As with fungal diseases, parasitic diseases of bones and joints are uncommon, but unlike fungi, they are not as readily associated with immunosuppression. Common forms include the following.

Lymphatic Filariasis

Nematodes of the Filarioidea family (roundworms) are transmitted to humans via insect bites, and the microfilariae eventually shut down the limb's lymphatic return, causing chronic edema and skin thickening, ultimately leading to elephantiasis. In early stages, knee pain is a common symptom, before the lymphatic changes are visible. Medical treatment with a combination of albendazole and ivermectin is curative. Once elephantiasis develops, it is irreversible, but with treatment the condition stops worsening (Fig. 11.8).

Fig. 11.8 Clinical appearance of chronic lymphatic filariasis involving the right lower extremity

Dracunculiasis

Dracunculiasis or guinea worm: The nematode, *Dracunculus medinensis*, infects humans who drink stagnant, larval-infested water. A year later, a painful vesicular lesion appears, most often near or below the knee joint. Eventually it ulcerates, exposing one end of the worm. The only treatment is to wrap the end of the worm around a stick or match and progressively "roll it out." This painful process can take hours or months. There is no medical or surgical treatment, unless the ulcer becomes secondarily infected, which is not uncommon.

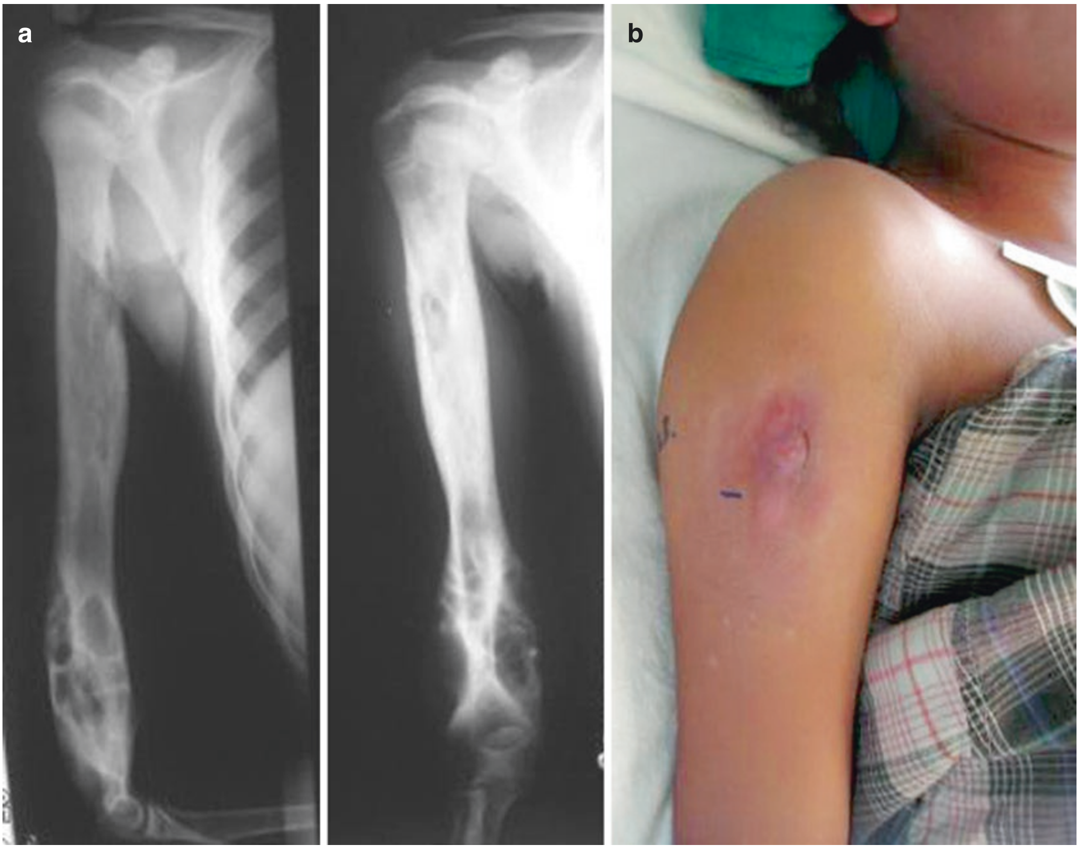

Fig. 11.9 (**a**) X-ray of hydatid osteomyelitis of the right humerus. (**b**) Chronically draining sinus of hydatid osteomyelitis

Trichinosis

The parasitic nematode *Trichinella spiralis* is ingested in undercooked or raw pork, game, or bush meat and forms cysts in striated muscle. Occasionally the cysts cause myalgias, but most are probably asymptomatic. Mebendazole is the treatment of choice and surgery is rarely needed.

Hydatid Disease (Echinococcosis)

Humans are accidental intermediate hosts that become infected by handling soil, dirt, or animal hair that contains eggs of the tapeworm echinococcus. The musculoskeletal system is rarely targeted, but the polycystic form can create cysts in the metaphyses of long bones (Fig. 11.9). Medical treatment with mebendazole is usually sufficient, but cysts jeopardizing the structural integrity of the bone need to be curetted and bone grafted.

Venomous Injection Injuries

The musculoskeletal system can also be involved with venomous bites or stings—of varying degrees of severity—from snakes, lizards, fish, marine invertebrates, scorpions, spiders, and insects (Fig. 11.10). Local providers are usually experienced in these matters, and their advice should be sought and followed. Envenomation by snakebite in particular can be life or limb threatening, and knowing the type of snake is helpful. Not every snakebite requires surgical debride-

Fig. 11.10 (**a**, **b**) Clinical appearance of a progressive necrotizing dermatitis in an elderly Bhutanese woman about a week after being bitten by a spider. (**c**) Appearance of the leg after multiple debridements. (**d**, **e**) Leg after extensive meshed STSGs. (Courtesy of Dr. Sam Baker)

ment or fasciotomy, so a careful clinical examination is of upmost importance. In doubt, it is better to decompress than miss a treatable compartment syndrome. However, there is no indication to decompress the muscles of a patient who presents late, with a well-established compartment syndrome of 2–3 days. This only creates wounds that will become infected.

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12 Rickets and Angular Bone Deformity

J. Norgrove Penny and Coleen S. Sabatini

Introduction

Angular deformities of the lower limbs are common in pediatric orthopedic practice in lower-income countries. In a study from Rwanda, angular deformities of the lower limbs were the most common cause of musculoskeletal impairment in children [1]. Limited access to services and delayed treatment often result in severe deformity not commonly seen in higher-income countries (Fig. 12.1). Areas with an increased prevalence, particularly in rural environments, raise the question of both nutritional and genetic causes, though few epidemiologic studies have been done. Deformities can originate at the physis, metaphysis, or diaphysis and include genu varum, genu valgum, and windswept deformities. Practitioners must identify the etiology of the deformity prior to planning limb realignment.

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Differential Diagnosis

Physiological bilateral genu vara in otherwise healthy infants will spontaneously correct by 2–3 years of age, after which genu valga can develop and resolve by age 5–7. The differential of pathologic pediatric angular deformities includes (1) posttraumatic or post-infectious, (2) Blount's disease, (3) vitamin D-resistant rickets, (4) nutritional (calcium or Vitamin D deficiency) rickets, (5) skeletal dysplasias, and (6) idiopathic.

Posttraumatic or Post-infectious

Inadequate access to primary treatment of osteomyelitis and fractures results in metaphyseal or diaphyseal malunion or deformity or asymmetric physeal arrest (Fig. 12.2). The deformity is usually unilateral and often accompanied by leg-length discrepancy.

Blount's Disease

Blount's disease is a developmental abnormality caused by disordered endochondral ossification of the medial proximal tibial physis, resulting in a multi-planar deformity, most commonly characterized as tibia varus. Blount's disease is thought to be caused by mechanical abnormalities, not metabolic ones. It occurs in

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Fig. 12.1 Severe genu varum deformities from Blount's disease

Fig. 12.2 Healed osteomyelitis of the femoral diaphyses with physeal growth arrest and varus angulation in a 7-year-old

infantile and adolescent forms. The infantile form is often bilateral but asymmetric, distinguishing it from physiological genu vara. Careful evaluation of the radiograph reveals typical physeal changes confined to the medial half of the proximal tibial physis (Fig. 12.3). The distal femoral physis is often normal, but in some cases an adaptive valgus deformity is seen. An alternate diagnosis should be sought if varus deformity is seen in the distal femur.

This condition is more common in children of African origin and should be distinguished from the Blount's seen in higher-income countries in obese patients. A review of 110 African children with Blount's disease found no evidence to support age of walking or weight as risk factors [2]. (See Chap. 41 for discussion of osteotomies.)

Rickets

For children in the developing world, rickets is the most common noncommunicable disease [3]. Rickets is caused by a failure of endochondral calcification resulting in widened and deformed growth plates. Though there are no internationally accepted diagnostic criteria, the usual findings are widened epiphysis at multiple locations (particularly the wrist), rachitic rosary, swollen knees, angular deformities of the lower limbs, bone pain with ambulation, and frontal bossing [4]. A wrist x-ray should be taken as non-rickets forms of angular bone deformity seldom affect the wrist (Fig. 12.4).

Worldwide, the most common cause of rickets is vitamin D deficiency; however, this is not the

Fig. 12.3 X-ray of a knee with the typical bony changes of Blount's disease: medial tibial physeal changes with adaptive valgus at the distal femur

case in a variety of countries in sub-Saharan Africa and Asia. In these low-income countries, calcium deficiency is the major cause of nutritional rickets [5].

Vitamin D-Resistant Rickets

Vitamin D-resistant rickets results from genetic abnormalities causing a defect of renal tubular function. Children present as toddlers with weakness and delayed walking, angular deformities, and enlarged epiphyses. Biochemical screening to differentiate nutritional from vitamin D-resistant rickets should be done if available. All children should be treated initially with vitamin D and calcium supplements as a trial. Treatment of vitamin D-resistant rickets is complex and requires a multidisciplinary approach with specialized medical colleagues.

Vitamin D-Deficient Rickets

True vitamin D-deficient rickets was previously thought to be rare in tropical countries due to abundant sunlight, except in cultures where individuals are covered or veiled. Recent studies show that in some environments where children are kept inside much of the day—informal settlements in Kenya for safety reasons or houses with few windows—vitamin D-deficient rickets is a problem [6, 7].

Calcium Deficiency

Calcium-deficiency rickets is the most common cause of angular deformity in lower-income countries yet is the least understood and is probably underdiagnosed [8, 9]. The past cases were likely to have been classified as idiopathic. Studies in Africa and South Asia show that calcium deficiency results from malnutrition due to a monotonous carbohydrate diet deficient in calcium and micronutrients while high in phytates—compounds found in whole grains, legumes, nuts, and seeds that bind to certain essential dietary minerals and slow their absorption [10–12]. Large deformities are common. Radiographs may show some widening or flaring of the metaphyses, but these changes are not as profound as in vitamin D-resistant rickets. Angular deformities occur in the metaphyses and diaphyses of long bones, especially at the knee, presenting as genu valga, genu vara, or

Fig. 12.4 (**a**) This infant presented with delayed motor milestones and was noted to have swelling at the costochondral junction ("rachitic rosary"). (**b**) A 4-year-old child with rickets and wrist swelling, a clinical sign of active rickets, (**c**) also had bowing of the lower extremities. (**d**) Classic radiographic findings in rickets include widening of the physes and flaring of the metaphyses

windswept deformity. Upper extremity and other weight-bearing joint involvement is rare. The presentation of windswept deformity should create a high index of suspicion of calcium deficiency. Biochemical analysis will be normal (Fig. 12.5).

Skeletal Dysplasias

These are a relatively rare but large and diverse group of genetic disorders, often with a positive family history. Patients are typically of short stat-

Fig. 12.5 Probable calcium-deficiency rickets in a toddler as angulation involves both the metaphyses and the diaphyses

ure with multiple physes or bone involvement in symmetric fashion (Fig. 12.6). Treatment needs to be individualized with the aim to maintain the mechanical axes.

Idiopathic Deformity

Where none of the above categories can be defined, the condition can be considered idiopathic. The deformities are usually mild and symmetric genu vara or valga.

Treatment

All children suspected of having rickets—nutritional deficiency or vitamin D-resistant—should be treated with vitamin D and calcium supplements. Foods rich in these elements should be encouraged. The role of whole small fish with their intact livers and skeletons cannot be overestimated. Crushed and made into a paste or porridge (Fig. 12.7), they are better than phar-

Fig. 12.6 Genu varum in a 3-year-old. Note the abnormal physes and metaphyseal changes at the proximal and distal femur and the proximal tibia. The diagnosis is epi-metaphyseal dysplasia

Fig. 12.7 Small whole fish from Uganda. Ground into a paste called *Kitobero* is a weaning food rich in protein, calcium, and vitamin D

maceutical products and are readily and cheaply available in many under-resourced countries [13]. To treat nutritional rickets caused by calcium deficiency, 500–1000 mg of elemental calcium daily is indicated, with the higher dose leading to faster healing [14], though healing may take longer than 24 weeks. Natural calcium sources such as limestone or ground fish are equally effective [15].

Angular deformities of the knees can improve dramatically in small children before the age of 5 or 6 if given nutritional supplements [10]. The use of long leg orthoses is controversial and difficult to implement. Those deformities remaining after treating the metabolic problem can be corrected either by "guided growth" techniques if mild, i.e., temporary hemi-epiphysiodesis by physeal stapling or plating techniques, or by osteotomies if more severe (see Chap. 37).

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13 Nonsurgical Principles of Fracture and Injury Management

Richard C. Fisher, Richard A. Gosselin, and Michelle Foltz

Introduction

Over the past couple of decades, younger generations of orthopedic surgeons in HICs have had a significant decrease in their exposure to nonsurgical treatments of musculoskeletal injuries. Surgeons in middle-income countries are experiencing a rapid transition from nonoperative to internal fixation of fractures. The current epidemic of road traffic injuries has helped push the speed of this transition as overcrowded hospitals cannot cope with the 6–10-week stays needed for adequate treatment of traction patients. But in more austere environments, nonoperative treatment remains the cornerstone of musculoskeletal injury management and provides an invaluable safety net [1, 2]. The following section is a brief reminder of basic principles of conservative techniques such as casting and traction.

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Casting

A cast immobilizes the fracture by preventing motion at the joints above and below the fracture and maintains reduction by providing external three-point fixation to counteract the inherent deforming forces. A fresh injury, particularly if the fracture is displaced, is always associated with some degree of swelling. The soft tissue injury takes precedence in treatment with attention directed to preventing neurovascular compromise. Prompt reduction, if indicated, is followed by the RICE principle of rest, immobilization, compression, and elevation to minimize the inflammatory responses of pain and edema.

In high-income countries, initial injuries are usually splinted or placed in traction before definitive surgical treatment. In resource-poor areas, acute injuries are usually splinted before final treatment in a cast, though there will be situations requiring definitive treatment at the initial visit. If a circumferential cast is applied,

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particularly after manipulation, we cannot emphasize enough that the patient should be admitted for elevation and observation, or if discharged, the cast should *always* be bivalved, with crystal clear and simple instructions to the patient and his accompanying entourage about the indications and technique for removal, as well as the usual instructions for elevation and cast maintenance. Mostly everyone has access to scissors or knives to remove a splint or bivalved cast; no one has cast cutters or spreaders to remove a circumferential plaster. For this same reason, we prefer plaster of Paris (POP) rather than fiberglass, even if it is used only as a final layer to give rigidity, because POP can be soaked off if the need arises.

Ideally the patient will return in 3–4 days to have the bivalved cast closed, by applying a few rolls of plaster. For patients presenting late with fractures that do not require manipulation, definitive casting can be done initially if further swelling is unlikely. However, if in doubt, follow the above protocol for recent fracture immobilization. Postoperative patients may also require immobilization. A well-padded back slab, three-sided gutter splint, or one half of a bivalved cast can be used for a few days until the limb is ready for definitive casting, either by closing the bivalved cast or applying a new one. A new cast is necessary if stress molding—stress applied while the cast is setting to prevent or correct an angular deformity—is necessary.

Small wounds or stitch removal can be managed through a window in the plaster, though monofilament nylon as skin closure can be left undisturbed under a cast for over a month. Windows have received a bad name because they are often improperly made or the cutout window was not replaced at the time of dressing or stitch removal leading to window edema (Fig. 13.1). The edema can lead to wound complications and permanently discolor the skin. Making and cutting a window are explained in Fig. 13.2.

Fig. 13.1 Window edema visible in the proximal window of this useless cast

Writing the date of injury, date the cast was applied, and date of removal will avoid confusion if records are inadequate or lost. Unless contraindicated, the wound or incision under a cast should be closed with resorbable sutures in the pediatric population.

In spite of all precautions and with the best of instructions, ultimately, the patient's compliance will determine the success of cast treatment. It is surprisingly common to see at follow-up casts that are totally ineffective because of poor POP quality (Fig. 13.3), overuse (Fig. 13.4), or self-customization (Fig. 13.5).

Fig. 13.2 (**a**) A thick, mounded underlying dressing clearly marks the area to be windowed. (**b**) Correct way to cut the window, tangentially to the cast. (**c**) Incorrect way to cut window, perpendicularly to the cast. (**d**) Window, once opened, is closed over a compressive layer of gauzes to prevent edema and secured with an elastic wrap

Materials

Fiberglass is lighter, more rigid per unit of weight, and relatively water resistant compared to traditional plaster of Paris (POP, gypsum plaster, calcium sulfate hemihydrate). It is rarely available in austere environments, whereas POP is universally available, in rolls of different sizes. It can be of uneven quality, depending on the amount of plaster/roll, age of the roll, and manufacturer. In hot, humid environments, plaster's half-life may be limited depending on how and where it is stored. It is bulkier, takes longer to set and to dry (up to 48 h), and softens if wet. If fiberglass is available, but only in limited quantities, it can be used as a strengthening outer layer over POP, lessening the cast's weight and making it more durable.

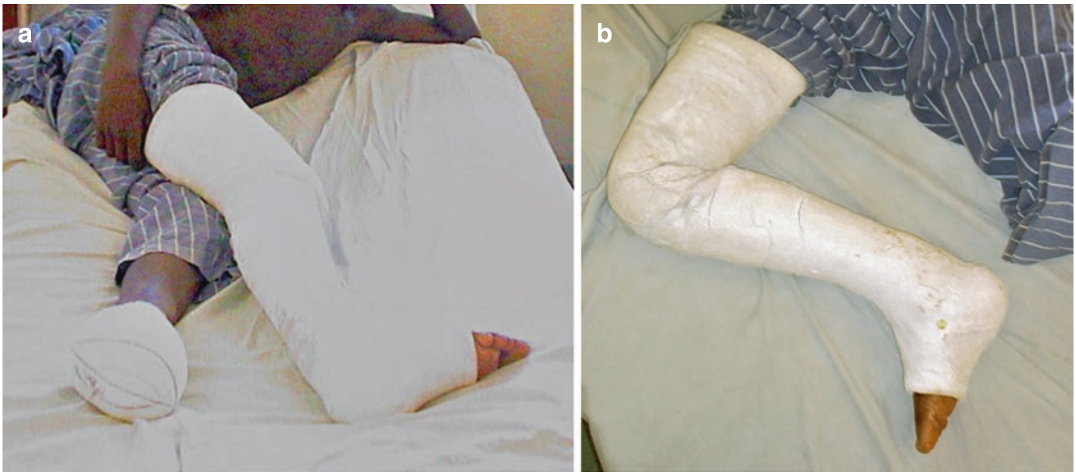

Fig. 13.3 (**a**, **b**) Poor-quality POP allows movement of the joint it is supposed to immobilize

Fig. 13.4 (**a**, **b**) Examples of well-worn POP casts with the footplates completely worn away with weight-bearing

Casting Technique

Stockinette should be used under the cast when available. It protects the skin and hair and helps prevent saw blade cuts or burns on cast removal. Leave excess stockinette at both ends of the cast. Avoid wrinkles or creases at joints by cutting the stockinette tube transversely and overlapping the cut edges.

Fig. 13.5 This patient customized his BK POP down to barely more than an ankle bracelet

Specialty undercast padding of cotton or synthetic may be available, but occasionally there are only large rolls of cotton batting. These are more difficult to use, as the layers must be separated before use and the cotton tears more easily and more unevenly. Cast padding should be rolled firmly but without tension, usually from distal to proximal, overlapping the previous layer by half its width, to achieve a uniform 6–8 mm layer—better slightly too thick than too thin. Extra cotton is used over prominences such as the fibular head or the malleoli; over areas particularly sensitive to pressure sores, such as the posterior heel; and under weight-bearing areas. The padding, like the cast itself, should be applied with all the joints in the desired position, to avoid creases and bunching that can cause pressure areas. Chinese finger traps or clove hitch loops of bandage to help immobilize and hold an extremity can prove useful to the unassisted surgeon (see Fig. 20.2).

Completely submerge a roll of plaster in a container of skin-temperature water. When bubbling has ceased, gently squeeze it to the point where it is barely, but still, dripping. Pressure at each end of the roll will prevent “bananaing,” and if the leading edge of the roll is first folded back on itself, it is easier to find when wet, saving time. Cast heating problems can occur if the water is too warm and with certain types of quick-drying plaster, excessively thick plaster layers, or when a damp cast is placed directly on the plastic covers of pillows and mattresses and covered with a thick blanket.

The plaster is rolled in a manner similar to the cast padding, holding the roll against the patient with gentle tension but not pulling the roll away from the limb or bunching the padding. Unroll the plaster using the thenar side of the palm, smoothing each turn of the roll to remove air bubbles that lead to delamination. Take small tucks when moving between different circumferences and crossing over flexed joints. The desired thickness of the cast will vary according to patient age, anatomical site of the injury, and proposed usage, but it should be uniform. Reinforcement slabs can be applied over areas of high stress such as the front and back of the knee, the sole of the foot and ankle, and the elbow.

After the penultimate roll has been smoothed, mold the plaster to conform to the anatomical contours, e.g., a forearm or leg cast should be oval, not round. Three-point pressure is gently applied with the moving palms, never the finger tips, to maintain fracture reduction until the plaster is set. Trimming excess plaster can usually be done with scissors, cast saw, or a scalpel blade. Take care that the plaster does not dig into the first web of the thumb and the distal palmar flexion crease is visible, allowing finger MP flexion. The dorsum of all toes, including the fifth, should be free of plaster to the MTP joints to prevent sores caused by rubbing on the plaster with toe dorsiflexion. Turn the stockinette or remaining cotton over the plaster edges with a last layer of POP to give the cast a finished appearance.

When no assistant is available, it is easier to apply long-leg casts by completing the below-knee part first and proceeding with the above-knee section after the lower leg and ankle molding have been completed and the plaster has semi-set enough to maintain its position. Make sure the junction between the two cast segments is well padded and smooth with no sharp or bent edges to dig into the skin. Unless contraindicated, plaster the knee in 20–30° of flexion. With enough knee flexion it is difficult—even for the most noncompliant patient—to bear weight. The cast can be bivalved after it has reached a leathery state and the two halves secured with an ace wrap before discharge. In spite of all precautions, many patients will come back with broken, wet, or a foul-smelling cast or painful pressure points under the cast. Do not disregard patients' complaints. It is better, albeit time-consuming, to redo a cast than to have potential limb-threatening complications of a poorly applied POP (Fig. 13.6).

Off-the-shelf cast boots are not readily available. Rubber sandals or flip-flops can be fashioned into a POP-protecting shoe (Fig. 13.7). Hospital workshops can make rubber or wood and rubber platforms that can be incorporated onto the POP as a "walking rubber" to save the cast's planter integrity and give a nonslip surface for weight-bearing (Fig. 13.8).

Take care when removing the cast. Injuries from the saw blade are possible, particularly in children and in paralyzed or anesthetized patients. Cast saw blades are often extremely worn and generate a lot of heat, creating possible thermal injury. Inserting two fingers between the skin and cast while cutting should avoid accidental cuts. A metal or plastic "protector"—looking like a long, thin, and more flexible ribbon retractor—may be available or can be made from local materials (aluminum finger splints or tongue depressor). This is slipped under the stockinette or cast padding to protect the skin from contact with the saw blade.

For applying cylinder POP, see https://www.youtube.com/watch?v=OzjASYsm5gM.
For AK POP applied in sections, see https://www.youtube.com/watch?v=W8RqXjojJE0.
For applying above elbow POP, see https://www.youtube.com/watch?v=4w76zbUHH-g.

Wedging Casts (Gypsotomy)

Depending on the age of the injury, some malalignment or loss of reduction can be corrected with POP wedging or gypsotomy, most often without anesthesia. Because fewer fractures in HICs are treated nonoperatively, cast wedging is becoming a lost art but is a useful technique for salvaging angulated forearm and tibial fractures in all ages and femur fractures in the pediatric population managed in spicas [3].

Opening wedges are made on the concave side of the deformity. They present fewer possibilities of pinching the skin than closing wedge gypsotomies on the convex side. Whether wedging a plaster of Paris or fiberglass cast, the principles are the same: identify the apex of the deformity; mark the proposed cutting line on the cast, making sure it covers more than half the circumference.

Identifying the site where the cast needs to be cut for wedging is made easier by taking an x-ray with a metallic marker (paperclip) taped on the cast at the presumed site *before* the gypsotomy (Fig. 13.9). If on first applying the cast you think it might need future wedging, tape the metal marker on for the first post-reduction x-ray, and mark this with a sharpie for later wedging when the plaster is set or after the fracture has become sticky.

Fig. 13.6 (**a**) The inadequate internal fixation of this femur fracture was supposedly "saved" by application of an above knee POP. (**b**) The poorly applied POP created a vascular problem, changing a femoral delayed union to an above knee amputation

Prepare precut wood, cork, or plaster spacers. Start by making ±10 cm perpendicular cuts at both extremities of the proposed wedge to prevent crack propagation. Then proceed with the gypsotomy. With one hand above as counter pressure, firmly and gradually apply distal pressure to open the plaster cut. Once in the proposed corrected position—usually calculated at 1 mm opening for each degree of desired correction, though one seems to always need a wider opening than anticipated—insert the spacer without allowing it to touch, or put pressure on the underlying skin, or curl the cut cast edges, and take the appropriate x-rays. More manipulation may be indicated, using a larger spacer, or the cast can be

Fig. 13.7 This patient fashioned a useful "cast shoe" from a rubber slipper, some string, and a rubber band that has protected the footplate of the POP and provided a non-skid surface

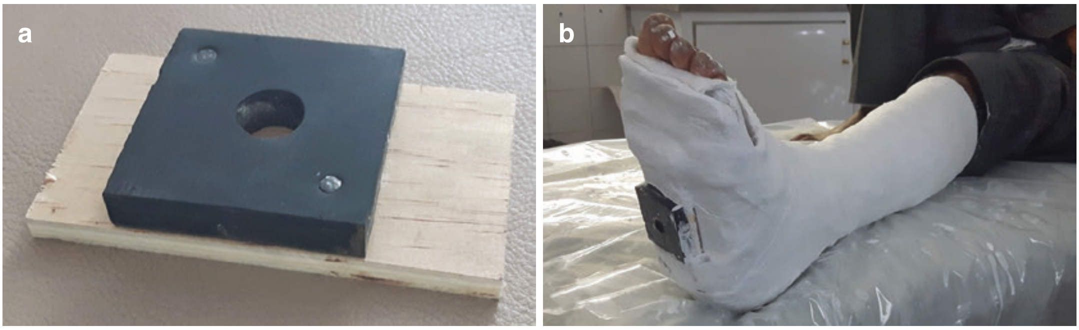

Fig. 13.8 (**a**) The hospital's workshop made this simple wood platform on which a square of hard rubber is nailed. (**b**) The "walking rubber" is incorporated into the footplate of a below knee walking POP with the rubber exposed

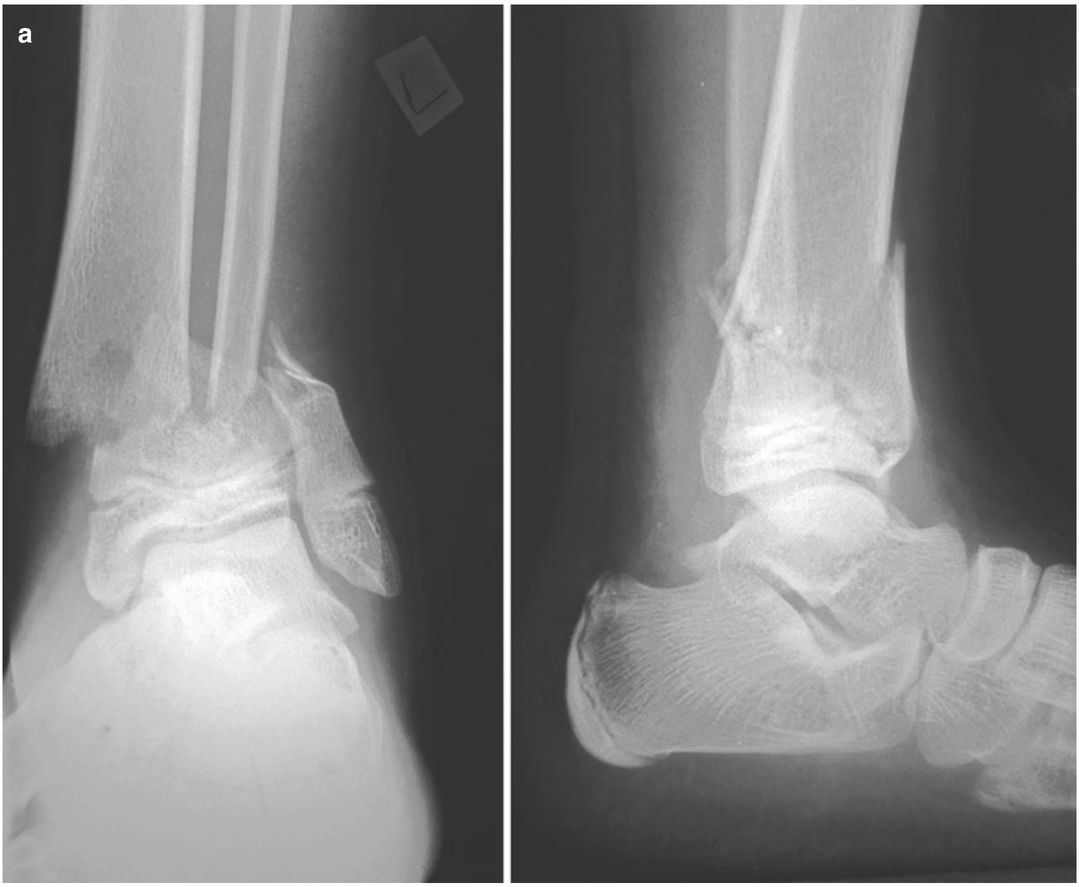

Fig. 13.9 (**a**) AP and lateral x-ray of displaced distal tibia-fibula fracture. (**b**) Residual angulation post-casting will be corrected with an anterolaterally based opening wedge. A metallic marker was placed immediately after casting and before the post-reduction x-ray to identify the optimal site for gypsotomy when the initial reduction was noted to be inadequate. (**c**) Gypsotomy line marked, in this case going beyond half the circumference. Small longitudinal cuts at both ends of the line are marked and cut first to prevent crack propagation. (**d**) The gypsotomy is kept open with precut pieces of wood that do not put pressure on the skin. (**e**) X-rays confirm an acceptable reduction *before* the cast is closed with one to two more rolls of POP. Make sure that any gap in the plaster has been filled with gauze or cotton to prevent window edema

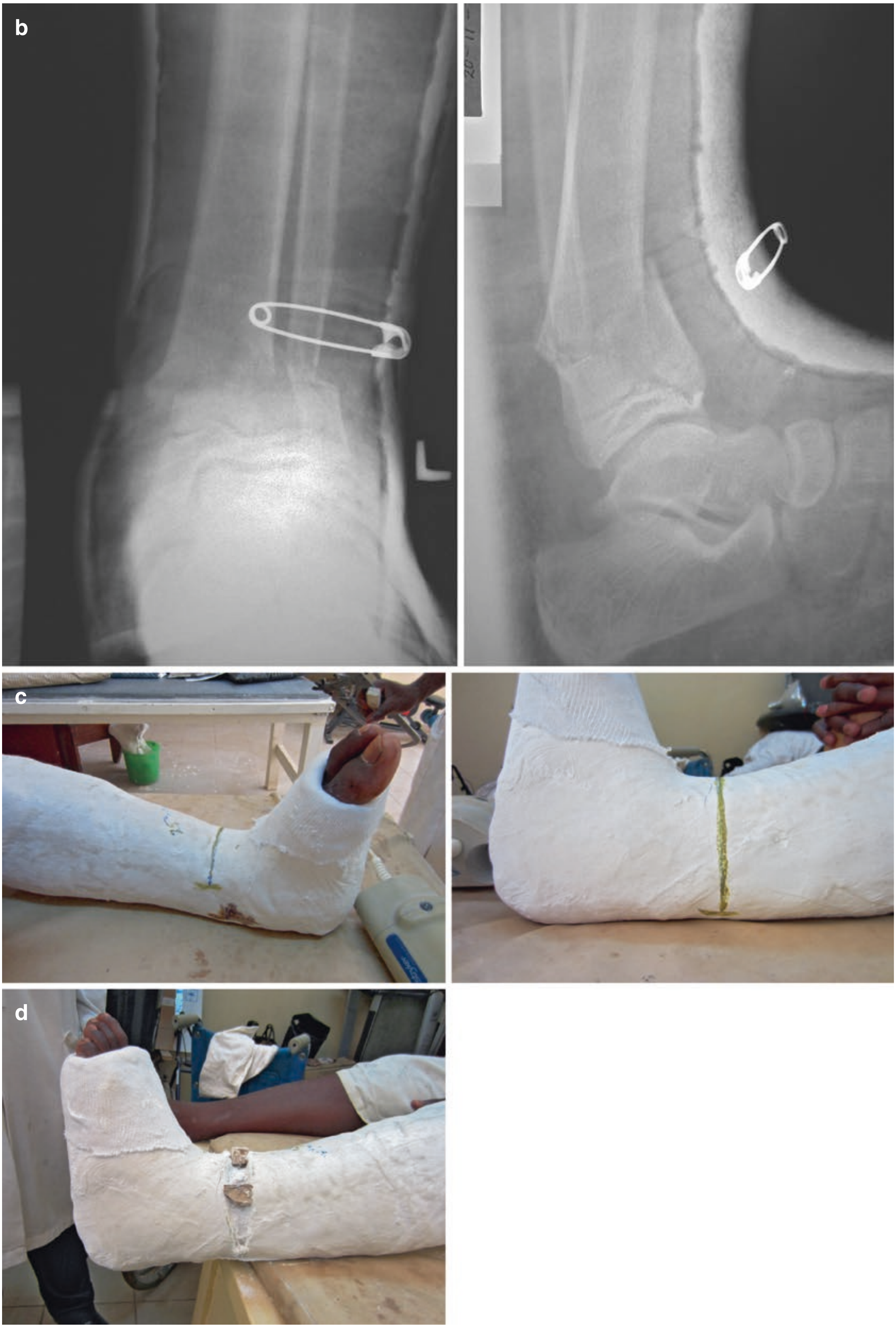

Fig. 13.9 (continued)

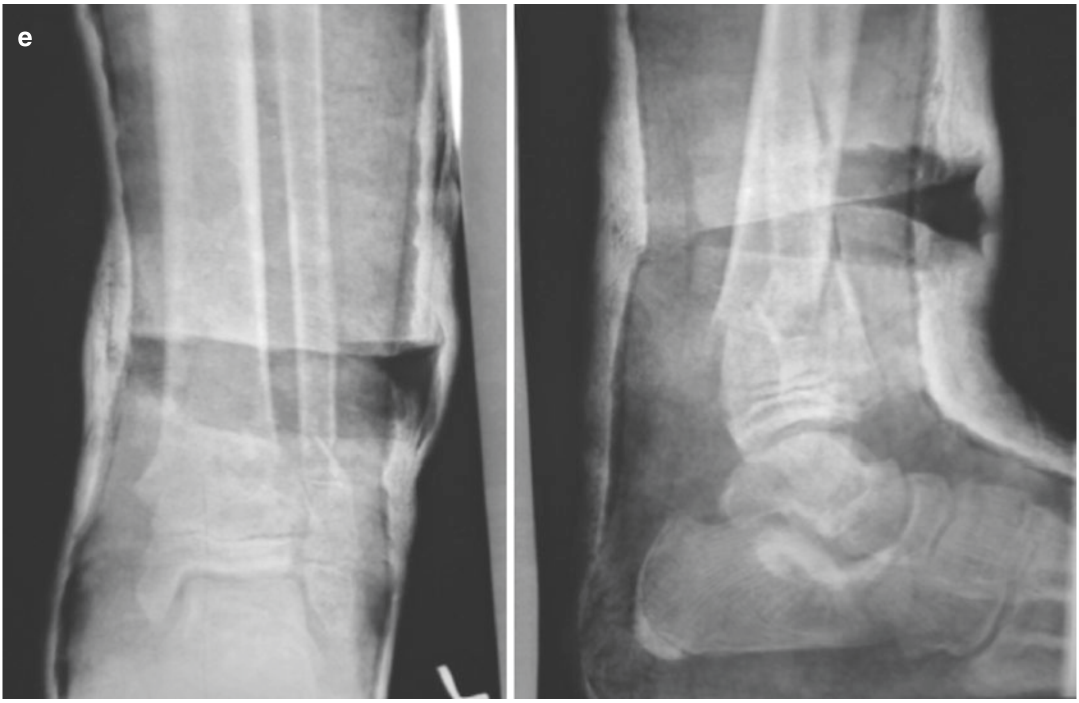

Fig. 13.9 (continued)

closed by applying a few rolls of material over the wedged area. Sequential wedging over several days to a week for progressive correction is possible, by using progressively bigger spacers and closing the cast when the desired correction is achieved.

Special Casts

Hip Spica

Hip spicas are uncomfortable and unwieldy for adults but are useful to rest the extremity after removal of a femoral ex-fix when a patient cannot be admitted for traction or in salvage situations. In most cases the patient will be able to stand during application while supported by two drip stands or crutches with the casted leg resting on a stool or box while applying a single-leg cylinder cast with a waist band. Pointers: cast the hip slightly abducted and flexed about 30–45°, to allow ground clearance. Knee flexion will depend on the weight-bearing status of the injury. Reinforce the connection between the pelvis and leg with extra plaster or fiberglass, and pad well sacral and other bony prominences. Hip spicas do not do well on obese patients.

Hip spicas for femur fractures are standard treatment and better tolerated in the pediatric population—up to about 25 kg body weight—whether applied as the initial post-fracture treatment or after a period of traction to allow early stabilizing callus (Fig. 13.10). Most hospitals have management protocols based on bed availability, personality of the fracture, proximity of the patient to the hospital, ease of transportation, and the philosophy of the local doctors. Variations include as follows: the type and length of traction, timing to spica application, type of spica—1.5 or single leg—where the spica is applied (i.e., OPD, OR, cast room), and type of anesthesia used.

When available, fiberglass is preferred as it is lighter, but the edges are sharp and should be covered with felt or extra cotton after trimming to allow rollback to produce rounded edges before the last rolls are applied. Spicas look neater and the edges wear better if stockinette is used.

Fig. 13.10 Right single-leg spica for femur fracture. Notice the right foot is free, the edges have been well padded to prevent skin problems, and the diaper is tucked underneath the cast

Prominences, especially around the sacrum, should be well padded.

A frame is usually available on which the child's buttock can rest and allow easy access for cast application (Fig. 13.11). If not, a makeshift one can be assembled with boxes, pillows, an upturned medicine cup, or the OR table's arm board. Place a small bag of IV fluid, folded towel, or sheet between the stockinette and the skin of the abdomen for chest expansion. One or two people, depending on the size of the child, need to hold the legs and maintain proper joint positions. This is particularly important after hip surgery, and a designated person (preferably the surgeon) is responsible to keep the limb in the desired position at all times throughout the casting.

A spica can be applied in one piece or in sections, beginning with splints and rolls around the thorax/pelvis from the xiphoid process and progressing distally to incorporate the hips. When this is set, the rest of the leg section is applied.

Hips are casted between 45 and 90° flexion with abduction, enough to allow perineal care. Knees are casted at 45–90°. The amount of flexion depends on the location of the femur fracture

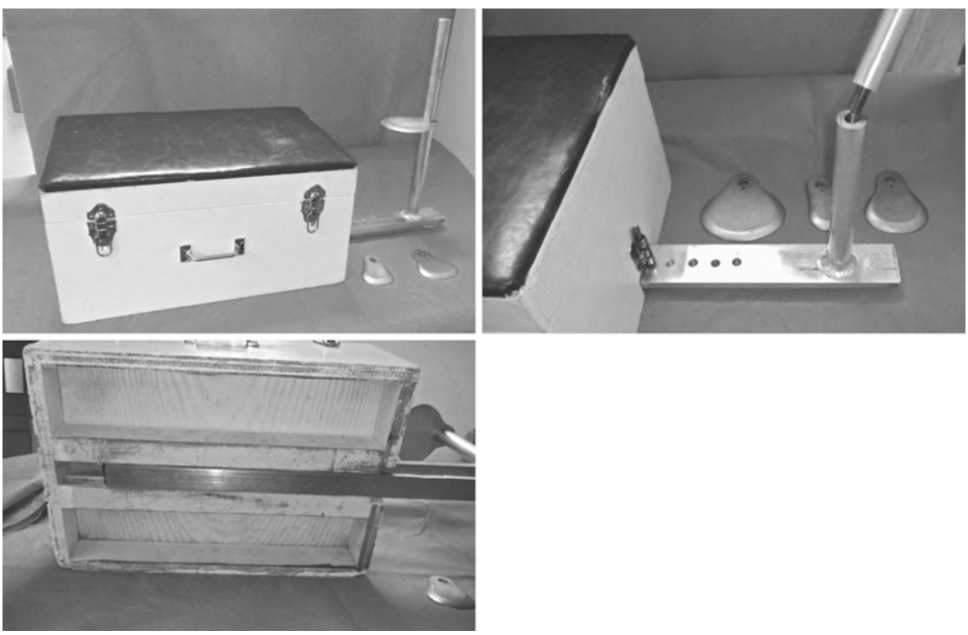

Fig. 13.11 (**a**) Example of a homemade portable spica table that holds the components and can be easily carried into the field. (**b**) Different-sized buttock support plates are easily exchangeable. (**c**) The length from edge of the chest support to the buttock plate is adjustable

(proximal fractures require greater flexion), how many legs are involved in the spica, and whether the child is allowed to walk. Mold the thigh into a few degrees of valgus as femur fractures often drift into varus. The foot is left free, as the sole pushing against the footplate of the cast can shorten the femur. A seven- to ten-layer-thick splint is applied laterally across the hip joint prior to the final roll to strengthen the cast, especially in a single-leg design. A bar between both legs strengthens the construct of a 1½ or double spica.

Precautions: (1) Do not first apply a short-leg cast and then apply manual traction, as there is risk of popliteal compression and compartment syndrome. (2) If a long-leg cast is first applied and converted to the spica, it is difficult to mold the femur, and the upper edge of the long-leg cast may cause focal pressure against the skin of the lateral thigh.

With the child off the frame, the buttock and perineal areas are trimmed with a cast knife, scalpel blade, or cast saw and the edges rolled, securing the stockinette with casting material or later, when dry, with tape. A small diaper must be tucked inside and under the cast edges before the child leaves the casting venue. A second diaper may be placed around the outside to support the first.

It is extremely important that the caregiver understands that the diaper—disposable or cloth and rubber outer pants—be stuffed up and inside the cast; otherwise the cast will become soiled, potentially causing skin breakdown. In small children a sanitary napkin can be used as the first diaper layer, especially in situations where disposable nappies are expensive. A rare but serious complication of spica casting is superior mesenteric artery syndrome, with duodenal obstruction or even occlusion. Many clinicians prefer to discharge spica patients only after they have had a bowel movement, especially if they live far away.

Minerva Cast

Where there are no halos or other braces, a Minerva cast can immobilize stable cervical fractures immediately post-injury or unstable fractures after 4–6 weeks in traction or surgery. They should not be used in patients with sensory loss in the areas that are under the cast. Patients should be able to sit comfortably on a stool to provide 360° access while the cast is applied. A soft cervical halter attached to a weight over an IV pole can be used to help stabilize the patient during cast application. If “body-sized” stockinette is not available, a T-shirt turned inside out—so the inside seams do not rub on the skin—will do. Pad well the bony prominences.

Place preformed plaster slabs longitudinally down the back of the head, neck, and thorax and around the neck and thorax and over the shoulders. Additional slabs are crossed, or spicaed, from the head to chest. Make sure the mandible is secure and the jaw cannot slip inside the cast’s neck but that the cast does not inhibit chewing. Trim to allow full ROM of the shoulders, and make sure the pinna of the ears are free. For female patients, the cast may need to extend more distally, allowing a cutout for the breasts. The cast controls cervical motion by three-point fixation between the sternum, occiput, and mandible (Fig. 13.12).

Hyperextension Cast

For thoracic fractures without neurologic injury, a hyperextension cast can be applied when the patient’s pain allows mobilization. It is easiest to place the patient prone between two trolleys, exam tables, or beds such that he feels secure and

Fig. 13.12 Application of a Minerva jacket. The chin support should not interfere with chewing but should support the mandible to prevent cervical motion

there is enough room between the two platforms for the plasterers to work. A spotter is advised to monitor and help hold the patient's position. To obtain true hyperextension with three-point fixation, the cast must come proximally to the manubrium and distally to the pubis using slabs and rolls of plaster. Trim the cast when the patient is supine or standing, making sure the axillae are free and he can flex the hips for personal activities. A cutout in the upper abdomen may help to relieve any feelings of claustrophobia and improve breathing (Fig. 13.13).

The greatest disadvantage of cast immobilization is joint stiffness. Elbows and knees should be

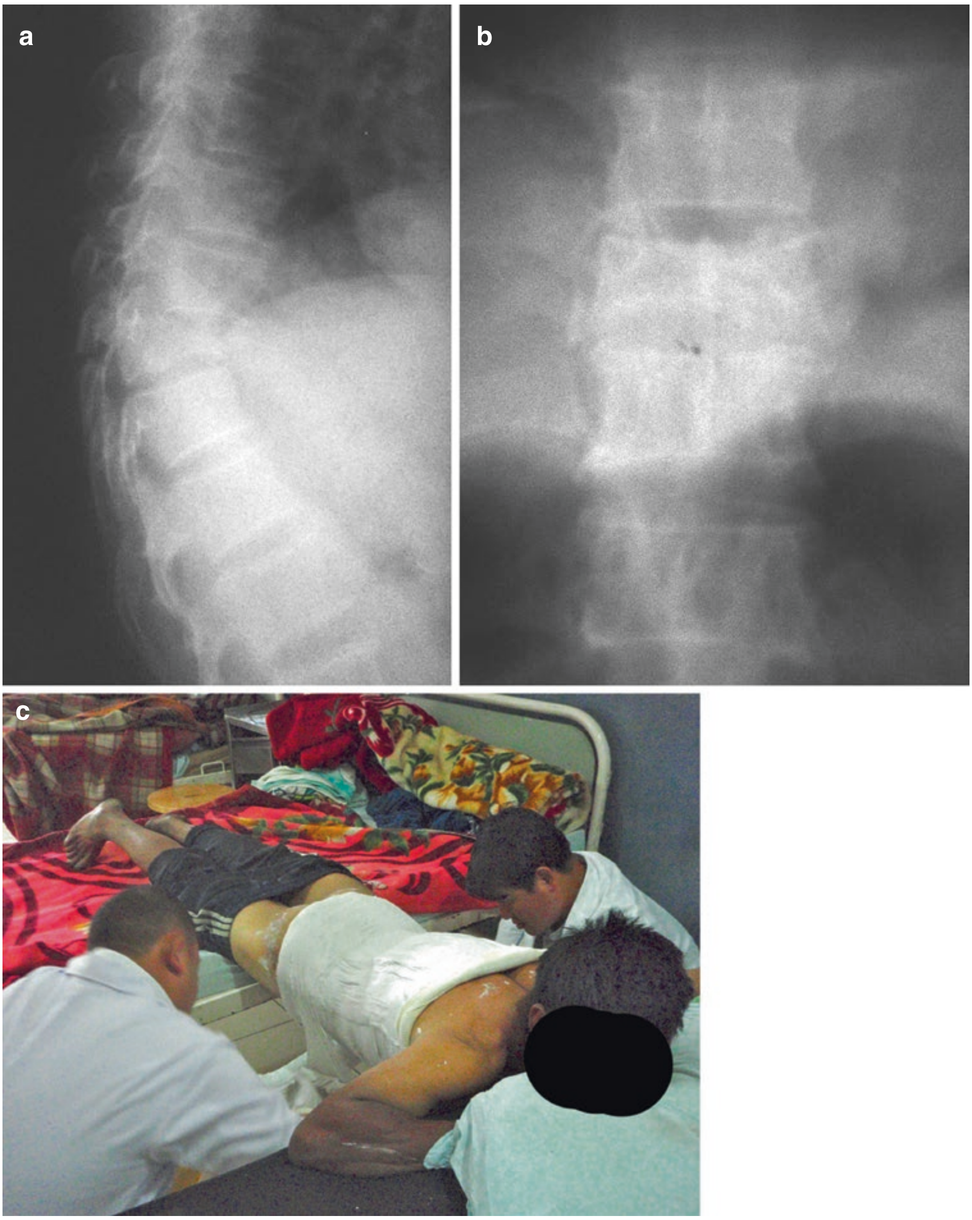

Fig. 13.13 (**a**, **b**) X-rays of an unstable flexion injury to the lower thoracic spine without neurological involvement in a Bhutanese farmer who fell out of a tree. (**c**) Application of a thoracolumbar cast in extension with the patient prone between two beds. (Courtesy of Dr. Sam Baker)

freed from plaster immobilization as soon as possible. Applying a Munster or patellar tendon-bearing (PTB) cast is a good alternative to a below-elbow or below-knee cast when more stability is needed. The basic principle is good molding around anatomical prominences to prevent distal rotation at the fracture site.

Munster Cast

The forearm is put in the desired position of pro-supination; the cotton is rolled to a thinner thickness than normal to allow better plaster molding. A short above-elbow cast is applied, making sure the internal shape around the distal forearm is oval, or what is called a "screw driver fit," and that the cast is well molded over both sides of the olecranon and around and over both epicondyles. When dry or in the leather state, the cast is trimmed as shown just above the olecranon posteriorly, proximal and around the epicondyles on each side, and 5–6 cm distal to the flexion crease anteriorly. This cast usually allows near full extension, full flexion, and no or minimal pro-supination. The more distal the forearm fracture is, the better the immobilization with this cast (Fig. 13.14).

PTB Cast (Sarmiento)

A short above-knee cast is applied with around 20° of knee flexion, well molded around the leg, and contoured snuggly along both sides of the patellar tendon and around the entire patella. It is trimmed to just above the proximal pole of the patella anteriorly and 8–10 cm below the popliteal flexion crease posteriorly. It is important that the ankle remains in neutral position and the footplate extends beyond the metatarsal heads. Full unimpeded knee flexion and extension should be possible before the cast is finished. As for every walking cast, a cast shoe or rubber heel centered in line with the anterior tibial crest should be used if available. Although called a patellar tendon-bearing cast, the weight is borne by the two leg bones rather than the patellar tendon. The proximal extension and snug molding confer rotational control (Fig. 13.15) (see https://www.youtube.com/watch?v=bixYtWz3IsU for a video on PTB cast application).

Traction [4, 5]

The purpose of traction is to provide a counterforce to the deforming muscle contractions across the fracture, making it possible to control motion, alignment, shortening, and pain. The fracture position is maintained or altered by manipulating the traction apparatus. The traction force is applied through the skin or the skeleton via a trans-osseous pin. The decision of which method to use is based upon the traction weight needed to control the fracture position. The skin will tolerate about 3–4 kg. Greater weight is likely to cause skin shear with superficial ulceration and painful blistering and can compromise the deep circulation leading to a compartment syndrome. The tightness of the skin wrapping to hold the strapping in place and the quality of the adhesive on the strapping limit this sort of traction to children or as a method to simply keep an adult's limb comfortable for a short time (Fig. 13.16).

Tincture of benzoin applied to the skin will help prevent blisters by keeping the strapping from pulling differentially on the skin. The bandage is wrapped in a figure of eight fashion with just enough compression to hold the strapping in place when weight is applied. Use ample padding and minimal compression over bony prominences and the peroneal nerve as it curves around

Fig. 13.14 (**a**, **b**) The Munster cast starts with a short above-elbow cast well molded around the forearm, along the olecranon, and over the epicondyles. (**c**) Trimming is done just above and around the epicondyles, (**d**) just proximal to the tip of the olecranon, and (**e**) 8–10 cm distal to the elbow flexion crease anteriorly. (**f**, **g**) Near full flexion/extension is possible, while (**h**) supination and (**i**) pronation are severely restricted

Fig. 13.14 (continued)

Fig. 13.14 (continued)

the fibular neck. Avoid contact of the adhesive part of the strapping and compressive wrapping around the malleoli. Prepackaged strapping for skin traction is manufactured to leave these areas free of adhesive with wide spreader bars to prevent pressure.

If one must devise their own skin traction, using wide tape, face the area of the stirrup over the malleoli with a reversed layer of tape and make sure the spreader bar is wide enough so the tapes do not touch these sensitive areas. When in traction the heel should be free from pressure. A non-sterile glove half filled with water or a small pillow or foam under the Achilles tendon will elevate and cushion the heel from the underlying surface. Heels often roll off the glove, and family members and the patient are recruited to maintain it in place.

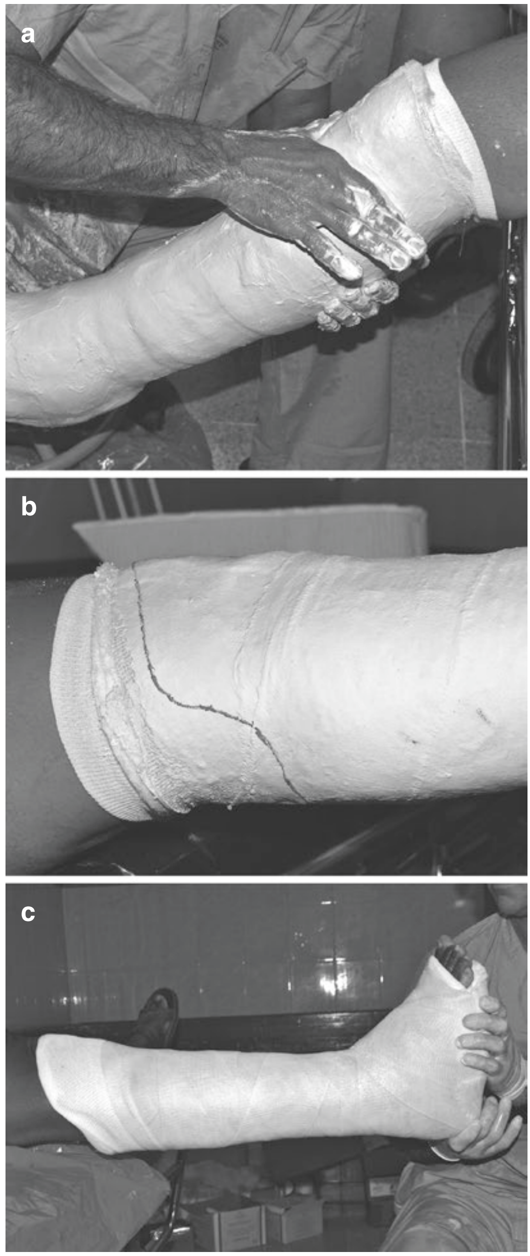

Fig. 13.15 The patellar tendon-bearing (PTB, Sarmiento) cast starts with a (**a**) low above-knee cast well molded over the calf, both sides of the patella tendon and around the patella. (**b**) The cast is trimmed just above the superior pole of the patella and distal to the popliteal flexion crease to allow unimpeded flexion and (**c**) extension

Skeletal traction is *not* synonymous with skillful neglect. Successful outcomes can be maximized by paying close attention to every step of

Fig. 13.16 Well-applied skin traction. Note the figure of eight application of the bandage without pressure on the malleoli. The spreader bar is well away from the foot and its width prevents pressure on the malleoli. This type of skin traction in an adult is for temporary comfort only, not as definitive treatment

the process: patient selection, pin insertion site and technique, and fracture and patient monitoring.

Pins come in many sizes and types: smooth and fully threaded (Steinmann) and centrally threaded (Denham). Threads afford better purchase in the bone, particularly in metaphyseal or cancellous bone. However, given enough time, every pin will loosen and eventually become infected. This occurs more rapidly with smooth pins. Threaded pins should be used when available, and they need to be well identified as such, as they must be unscrewed for removal, not just pulled or hammered out. In general, the biggest pin should be used, as long as it is less than one third the diameter of the bone at the site of insertion—the same principle for choosing the size of ex-fix pins. An alternative still seen is a K-wire and tensioner stirrup, using the same principle as for an Ilizarov-type apparatus.

Pins for skeletal traction are easily placed in the outpatient department using sterile technique and local anesthesia. In many sites, pins are reused: they might not be perfectly straight and the tips are often blunt. The use of power for insertion is discouraged, as it creates thermal necrosis and may lead to premature loosening, infection, and formation of a ring sequestrum (Fig. 13.17). Pre-drilling with a smaller drill bit before hand inserting the pin makes the job easier without fear of thermal damage. Gently tapping the pin at the point of bony contact, even if using a hand drill or T-handle, can ease insertion and avoid slipping off the bone. Where pins are disposable, cut one side close to the skin, generously paint the skin and tip with Betadine or chlorhexidine, and extract the pin by the uncut, long end with a pliers if unthreaded or a T-handle if threaded. Where pins are reused, the whole pin needs to be prepped and care taken during removal, especially if the pin is slightly bent. Grossly bent pins should be cut and discarded, no matter the general protocols on pin salvage.

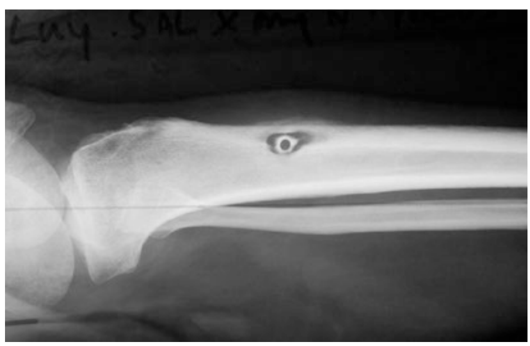

Fig. 13.17 X-ray of a large ring sequestrum from a proximal tibial traction pin that became infected

Pin Placement

For lower extremity injuries, the preferred sites for traction pins are the distal femur, proximal tibia, distal tibia, or calcaneus and for upper extremities the olecranon. In children there are epiphyses at these locations and care is needed to stay well clear of the cartilaginous growth plate and perichondral ring. The general principle is to put the pin in the middle of the bone, perpendicular to the axis of traction, and starting at the "danger" side and ending at the "safe" side.

For femur, pelvis, and acetabular injuries, a proximal tibial pin is commonly used. Always rule out an associated knee injury before inserting the pin. In adults the proximal tibial traction pin is started from the lateral side and placed about 2–3 cm distal and posterior to the tibial tubercle. The lateral start prevents injury to the peroneal nerve by an exiting pin. After a sterile prep, anesthetize the skin and periosteum on both sides. Make a 1 cm incision with a #11 blade. The pin should be parallel with the bed, while the leg is in neutral rotation and at 90° to the long axis of the limb. These relationships may be difficult to evaluate by the operator. The observations and guidance of an assistant from the foot of the patient, as well as moderate traction and stabilization of the extremity, will help keep the pin from going askew.

A hand drill or T-handle works well to advance a Steinmann pin through the bone. In most institutions drills of any sort are rarely present in the OPD or ED, making a mallet a common insertional tool. If the pin exit misses the area initially anesthetized, inject more local in the appropriate location. When the skin becomes taut over the advancing pin tip, use the #11 blade to make a small exit wound. Place a sterile dressing on the entrance and exit sites and attach the stirrup. Because of similar concerns for nerve or arterial injury, place femoral and olecranon pins from medial to lateral.

Traction pins in the distal femur are commonly used in children and placed at the level of the beginning flare of the condyles, opposite the upper pole of the patella, and slightly anterior to the longitudinal sagittal midline of the femur. They are safer than tibial traction pins as growth changes in the proximal tibia can occur following even well-placed pins. The greater bulk of soft tissue in the distal femur in adults makes such placement more problematic (see http://www.aovideo.ch/published/player.2.aspx?id=90092eem0198 for AO video on prox tibia and distal femur pin placement).

Calcaneal traction can be useful for short-time treatment of tibial fractures, especially those with significant soft tissue injury when external fixators are not available. These pins are placed 1 cm distal and posterior to the tip of the lateral malleolus. In this position and placed parallel to the sole of the foot, the pin is well away from the posterior tibial nerve and vessels. Pins in this area often become loose and should not be in place more than 2–3 weeks. Pay particular attention that the heels are well protected from pressure. A traction pin in the distal tibia, placed from medial to lateral, 3 cm proximal to the ankle joint will give better bone purchase than a calcaneal pin.

Lower Extremity Traction

The simplest and most commonly used traction is Buck's traction, also called Buck's extension, and is employed mainly as temporary immobilization and pain control for abnormalities proximal to the knee using skin traction or a foam boot. Using the same skin traction attachment, this can be converted to Russell's traction (Fig. 13.18), which is useful in treating femoral fractures in children up to the age of about 10 years, or 22 kg weight. It has a complex geometry which doubles the pulling force for a given weight and is easily adjustable to maintain alignment.

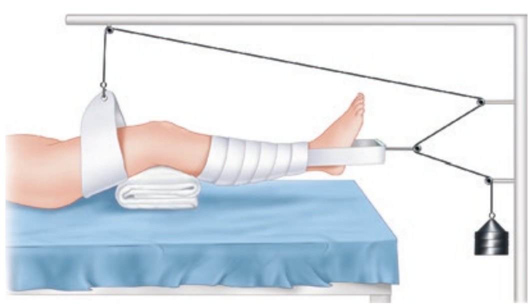

Fig. 13.18 Setup for Russell's traction

Bryant's or gallows traction is used in infants or children up to 2 years of age or 10 kg but entails the risk of vascular compromise to both the injured and non-injured leg and is rarely used in HIC. However, it is still commonly employed in austere environments because it is cheap and easy to monitor (Fig. 13.19). Local nursing staff and practitioners are usually familiar with this technique. Whether with a fixed or balanced arrangement, both legs are placed in traction until the infant's buttocks are elevated just off the bed. Both limbs need vascular checks hourly during the first 24 h. Never cover the feet so that they cannot be directly observed. Regularly monitor the traction for skin blisters. Complaints of pain or other concerns voiced by the child or caregiver need to be addressed. Early spica casting is indicated as soon as the fracture is sticky, usually before the end of the second week. In less austere environments where pre-made splints are available, the Pavlik harness as a "soft" spica can be used for femoral fractures in this age group.

Fig. 13.19 Child in Bryant's (gallows) traction. The buttocks are barely elevated from the bed

When more weight is needed for older children, skeletal traction is used. 90–90 traction (Fig. 13.20) works for children up to about 8–10 years old, but adolescents or adults tolerate it poorly. Balanced suspension traction is useful for older children and adults and can be set using slings or a Thomas splint with a Pearson attachment (Fig. 13.21).

90–90 traction is particularly useful for controlling subtrochanteric or high femoral fractures to overcome the flexion pull of the iliopsoas on the proximal fragment. In young children one can apply this using skin traction on the thigh com-

Fig. 13.20 Adolescent in 90–90 traction with proximal tibial pin. Distal femoral pin is also an option

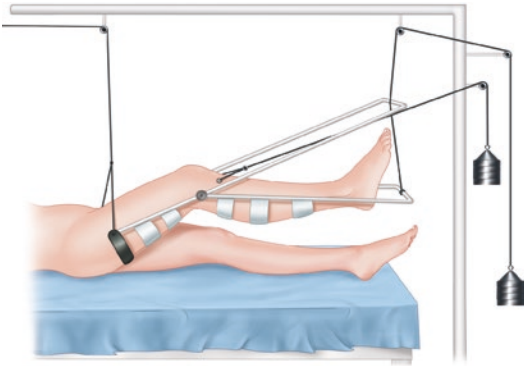

Fig. 13.21 Setup for Thomas-Pearson traction

bined with a sling or a lightweight below-knee POP supporting the lower leg. In the heavier child, a femoral traction pin is used with the lower leg in a sling. For adolescents and adults who do not tolerate the 90–90 traction, a compromise—such as a Bohler-Braun frame with traction pulling along the long axis of the thigh— will often produce the necessary hip flexion. Angular malalignment can sometimes be corrected by adding a second skeletal pin, pulling in a different vector (Fig. 13.22) (see https://www.youtube.com/watch?v=nu9xgb1mOu8 on how to apply skin traction and Thomas splint).

Fig. 13.22 (**a**) A comminuted supracondylar femur fracture with minimally displaced intercondylar component (T-type) treated initially with proximal tibial traction. The residual posterior angulation was unacceptable. (**b**) The tibia traction pin was removed, and two Steinmann pins were inserted in the distal fragment, to keep the intercondylar component reduced and allow traction using different vectors to correct the angulation. (**c**, **d**) Traction setup, with the patient comfortable on Bohler-Braun frame. The short-leg cast immobilizes an ankle fracture. Notice date and duration written on the POP and the water jugs used as weights

As a general rule of thumb for adult femoral shaft fractures, traction should start at about 10–15% of body weight. Traction in the 10–12 kg range is often needed, requiring at the outset larger pins to prevent bending and causing skin problems and difficulty in removal. X-rays taken in the radiology suite are usually done without traction and therefore useless and unnecessarily painful. When portable x-rays are available, AP and lateral views should be taken after 48–72 h and weekly for the next 3 weeks. Overriding by 1–1.5 cm is acceptable as long as alignment in both the frontal and sagittal planes is adequate (less than 10° of varus/valgus and 15° of anterior/posterior angulation). Distraction leads to nonunion and should be avoided, decreasing weights as needed.

Without x-ray, alignment is judged on a clinical basis and length determined by comparison to the non-injured side with a tape measure or observation. After 3–4 weeks, the fracture is sticky enough that tinkering with weights will have little beneficial effect. Before removing the traction pin—usually between 6 and 10 weeks—the patient should have palpable painless callus, no motion at the fracture site on forceful manipulation, the ability to lift the leg from the bed without pain, and x-ray evidence of ample bony callus.

In many places Bohler-Braun frames are used almost as a routine (Fig. 13.23). They can be used with skin, skeletal, or no traction as a place simply to elevate and rest the leg. Unless the hospital is supplied with various-sized frames, it is not easy to control a fracture in this nonadjustable frame, and it has a high complication rate with knee stiffness, skin breakdown about the buttocks, upper thigh and heel sores, and equinus contracture. If used, it requires close monitoring.

Perkins traction is one of the most versatile and functional traction setups (Figs. 13.24 and 13.25). Traction is applied with a proximal tibial pin. It uses no external frames or splints but requires a bed in which the distal third of the mattress and frame can be removed or folded out of the way while maintaining tibial traction, to allow the patient to sit and exercise the knee. The flexed knee position helps to control the femur in the correct rotation. It is useful for femoral frac-

Fig. 13.23 Typical adult male ward with most patients in skeletal traction, many on Bohler-Braun frames. Note the bed blocks elevating the foot end of the beds

Fig. 13.24 Perkins traction setup, with patient doing active (**a**) extension and (**b**) flexion exercises in a bed with a detachable distal frame so the mattress can be folded out of the way and allow sitting. (**c**) In time the exercises can be done with the patient standing

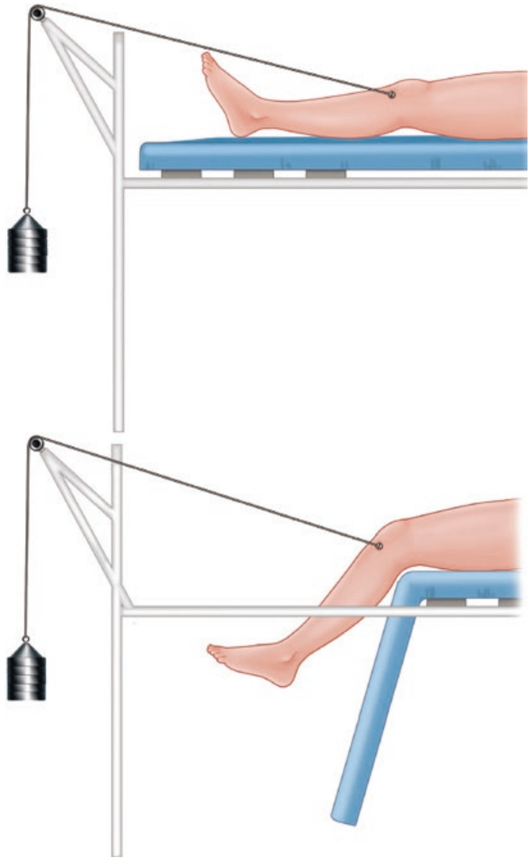

Fig. 13.25 Illustration of Perkins traction with mattress folded down to allow knee flexion

tures from the supracondylar to intertrochanteric areas. If the bed setup for Perkins traction is not available, a modification, "semi-Perkins" can be set up using a Bohler-Braun frame and temporarily removing the taping or support from under the calf on the frame. This allows active ROM of the knee while still maintaining a more flexed position of the hip in the frame for sub- and intertrochanteric femur fractures (Fig. 13.26).

The first few days of exercises in Perkins traction are painful and may require analgesia and "encouragement," but pain is replaced by discomfort more rapidly than one would expect. This method is time demanding on physiotherapy as the exercises should be supervised, at least at the beginning, and done twice a day for at least 30 min. When it is used

Fig. 13.26 (**a** and **b**) This patient's intertrochanteric femur fracture was poorly aligned when in straight Perkins traction. In a Bohler-Braun frame with hip flexion, the fracture alignment is maintained, while in a "semi"-Perkins arrangement, he is able to do active knee flexion and extension exercises. After 4–6 weeks, when the fracture is sticky, he can be converted to "full" Perkins

to its full advantage, it is not uncommon to see patients with 90° of knee flexion by the fourth week. This method is thought to promote earlier and stronger callus but possibly at the expense of a slightly higher pin tract infection rate [6].

Most lower extremity fractures treated in traction will benefit from elevation of the foot of the bed on bed blocks or stacked bed blocks to gain sufficient elevation. These are blocks of wood that raise the end of the bed. They can easily be made in the hospital's workshop or in the local bazaar, and their use should be part of nursing routine.

Few hospitals will have calibrated weights that fit onto a weight hanger. Some hospitals use bags of IV fluid, with easy calibrations of 1 l equaling 1 kg. Empty water bottles filled with sand can also be used. Pre-weighed sand bags are another option, but local rocks—pre-weighed, labeled, and hung in a canvas bag—are the most common weights. In spite of all precautions, some resourceful noncompliant patients will find ways to negate the discomforts of prolonged traction (Fig. 13.27). Properly rotating traction pulleys and other components are often old, missing, and substitutions abound (Fig. 13.28).

The general principles applicable to patients on prolonged bed rest apply to those in traction: good nutrition, DVT prophylaxis, avoid pressure sores (particularly heel and sacral areas), standard daily pin management, active and passive mobilization of all joints, and in particular, prevention of equinus deformity (Fig. 13.29). Exercises in traction are extremely important, and an active physical

Fig. 13.27 This patient had a family member rest the traction weight on the bed handle, negating its purpose. Note the improvised "runner" to keep the traction rope abducted, the bag of rocks, and the bed blocks

Fig. 13.28 Makeshift anti-sliding pulley apparatus

Fig. 13.29 Patient actively preventing equinus deformity with leg elevated on pillows and a Bohler-Braun frame

Fig. 13.30 Dunlop's traction

therapy team will increase the success of this treatment. Patients should be taught isometrics, bed push-ups from a sitting position, bridging, and range of motion of all joints for which there is no contraindication. An overhead trapeze or ropes attached to a Balkan frame or the ceiling will go a long way to improving a patient's general physical condition. A program of upper extremity exercises using weights, heavy stones, or bricks will help occupy patients' long hours and prepare them for crutches. Just as using traction to treat fractures is not a license for benign neglect, a traction ward is not a lifeless space of patients waiting in endless boredom. Well-run traction wards should be vibrant with patients active in their rehabilitation.

Upper Extremity Traction

Upper extremity traction is used much less often than lower extremity traction. It might be useful on occasion as Dunlop's traction (Fig. 13.30) for

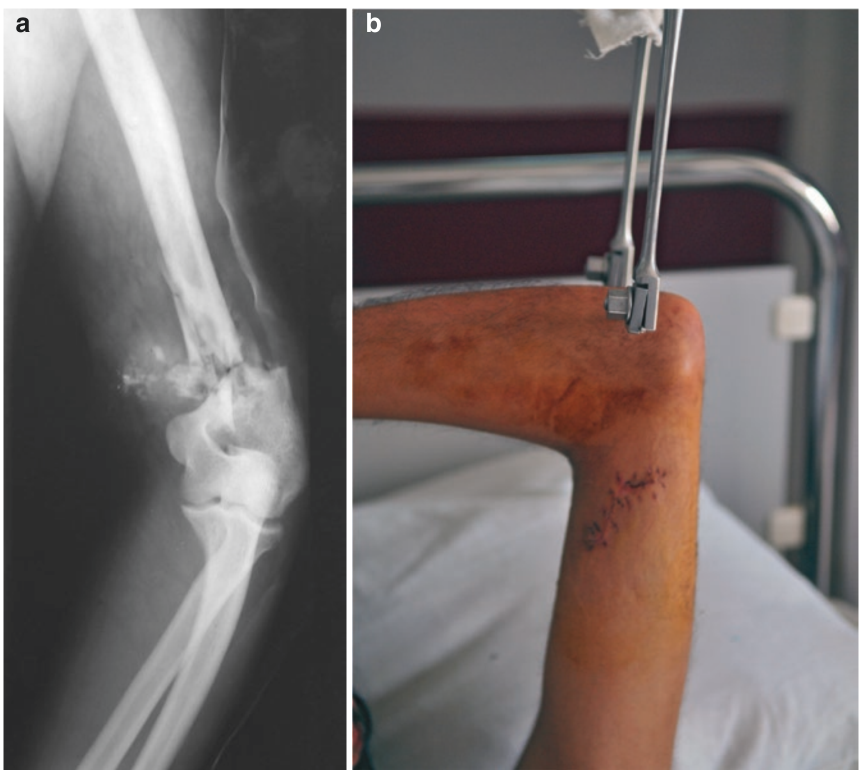

Fig. 13.31 (**a**) X-ray of GSW with comminuted distal humerus fracture. (**b**) Trans-olecranon traction. (**c**, **d**) At around 2–3 weeks, the fracture is sticky enough to be immobilized in an above-elbow POP, which is applied while the patient is still in traction. (**e**) Once the POP is partially applied and set, the pin can be removed and the cast completed

Fig. 13.31 (continued)

elbow injuries in children, but care must be taken to avoid vascular compression with a tight skin wrap. Neurovascular status should be continually monitored. Skeletal olecranon traction is useful for elbow and distal humeral injuries in adults (Fig. 13.31). It can be arranged so the pull is horizontal, with the forearm hanging from an IV pole, or overhead, with just enough weight to slightly lift the shoulder off the bed and the forearm resting at 90° in a sling. Active elbow motion while in traction should be encouraged.

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14 Basic Plastic Surgery for Orthopedic Surgeons

Nadine B. Semer

Wounds

Wounds are a common problem throughout the developing world, and closure options are often a source of confusion. The history for a wound should include the following: causative event, chronicity of the wound, clinical course, and current treatment as well as a history of diabetes, tobacco use, malnutrition, HIV, and tetanus immunization. Examination of the wound will determine if it is clean, healthy, infected, or necrotic. All infected and necrotic tissues need to be debrided and the infection under control before closure.

Primary Closure

Primary wound closure requires the fewest long-term resources and the shortest wound healing time and is usually appropriate for patients who present within 6–8 h after injury (up to 24 h for face and some scalp wounds). If the wound cannot be closed without tension, it is better to leave it open to heal by secondary intension, create a flap, or skin graft.

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Delayed Primary Closure

Delayed primary closure is appropriate for wounds that are best treated by primary closure but are over 6 h old, have questionably viable tissue at their base, or would have a very tight skin closure if closed primarily.

The wound is cleaned, packed open, and in 48–72 h reevaluated to be closed or re-debrided. It is useful to pre-place the skin sutures at the time of the first procedure. If closure is possible at the reevaluation, the pre-placed sutures obviate the need for a second anesthetic. In austere environments, late presentation of wounds is common, making delayed primary closure a useful tool.

Secondary Closure

If the patient shows up many hours after injury or there is evidence of significant wound contamination, ongoing infection, or tissue necrosis such that primary closure is not possible or would be done under tension, it is best to clean the wound, debride the nonviable tissues, and leave it open to heal secondarily with regular dressing changes.

Local Care and Dressings

Studies show that wounds heal best in a moist environment and there are many synthetic dressings and gels for wound care, but these are expensive and unlikely to be available. Wet to

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dry saline or dilute Dakin's solution dressings work well. Availability of gauze can also be a challenge. Dressings are best changed twice a day, though daily may be all that is possible (Boxes 14.1 and 14.2).

Box 14.1 Wound Cleaning Solutions

Saline Solution

Boil a liter of water for 15 min in a covered pot. Add 1 tsp. (5 ml) of table salt or cooking salt to the boiled water. Allow to cool, then store in a container with a tight lid. *NB*: this solution should not be used as an eyewash solution.

Dakin's Solution (Dilute Sodium Hypochlorite Solution)

For ¼ strength solution:

To a liter of NS, add 1.5 tsp. of Clorox (sodium hypochlorite solution 5.25% or plain household liquid bleach not concentrated). For ½ strength, double the Clorox. The container should be protected from light by wrapping it in aluminum foil and used within 3 days.

Box 14.2 Sugar Dressings

Sugar, as well as honey, has been used on open wounds including burns for centuries. It may work by decreasing wound pH, promoting epithelialization, or decreasing tissue edema through osmotic effects. In many areas, it is cheap and readily available.

Place gauze moistened with Betadine or saline onto wound. Coat this with sugar (~0.5–0.75 cm thickness). As the sugar draws moisture from the wound—an important component of the antibacterial properties of this dressing—the sugar will liquify. When this occurs, bacterial growth is promoted, so it is critical to change the dressing or add more sugar several times/day.

Negative-pressure wound therapy (NPWT) devices are frequently used in high-income countries to deal with problem wounds without resorting to flaps or grafts. Though presently expensive or nonexistent in low-income countries, a number of options using readily available materials are outlined in Appendix 4.

Skin Grafts

The following wounds will need a skin graft or flap because secondary closure will result in scar contracture that can severely limit function or cause significant disability:

- Wounds that will take more than several weeks to heal
- Wounds with exposed tendons, bone, or nerves
- Wounds in creases—antecubital fossa, dorsum of the ankle, back of the hand, and axilla

A split-thickness skin graft (STSG) is a partial thickness graft that preserves some of the dermis at the donor site, allowing it to heal on its own. A full-thickness skin graft (FTSG) takes the full thickness of the skin for the graft, requiring the donor site to be closed primarily.

Skin grafts receive their circulation from the recipient bed, making it critical that the wound is clean and the graft sutured in place. To prevent shear forces and promote vascular ingrowth at the graft-bed interface, the graft must be secured with a tie-over bolster, bulky dressing, ex fix, or plaster splint and left undisturbed for 5–7 days. On less than optimal surfaces, an STSG has a better chance for successful take than a thicker FTSG. An STSG can be used on wounds with exposed bone or tendons only if the thin, vascular overlying periosteum or peritenon is intact.

STSG

Most hospitals in austere settings have Humby or Watson knives to harvest an STSG (Fig. 14.1).

Fig. 14.1 The operator is holding a Humby knife at a 45° angle while taking the STSG. A broad sterile wooden board puts pressure on and flattens the skin ahead of the knife

Fig. 14.2 The Paprika sign of small punctate bleeding vessels on the surface of an STSG donor site

The thickness setting should be 0.011–0.015 in. (0.25–0.4 mm); however, the dialed-in calibration on the knives is rarely reliable. To ensure proper graft thickness, adjust the opening of the blade so that the beveled edge of a #10 blade fits snuggly into the opening.

The most common donor site is the thigh. Wipe off any antibacterial solution that was used to prepare the site. Apply a sterile lubricant, such as mineral oil or Vaseline from a Vaseline gauze, to both the donor site and the instrument used to harvest the graft.

Technique

1. Have an assistant flatten the donor site by placing tension on the skin with gauze or a wide flat object.
2. Hold the Watson or Humby knife with the sharp edge at a 45° angle to the skin.
3. With a back-and-forth motion, run the knife slowly over the tight skin.
4. As the graft skin is being taken, look at the wound. If fat is seen, the graft is too thick. If no pinpoint areas of bleeding are seen (paprika sign), it may be too thin (Fig. 14.2).
5. When enough graft has been harvested, cut the skin graft from the donor site with scissors (https://youtu.be/g_JD37smUGo).

Care of Donor Site

If local with epinephrine was not used at the start of graft harvest, apply a gauze wet with epinephrine solution (add 500 ml of saline to 1 ampule of 1:1000 epi) to the donor site to control bleeding. Treat the donor site like a superficial burn, covering it with an adherent plastic dressing or a single piece of Xeroform gauze. Remove the dressing at 24 h, leaving the Xeroform open to air. It will form an eschar that will separate over the next 2–3 weeks.

FTSG

Primary donor sites for FTSG are the mobile skin of the lower abdomen, inner upper arm, and the preauricular area where the donor site can be closed primarily. Cut through the full thickness of the skin, and when the graft is free, place the epidermis side down, draped over a gauze-covered finger, and using sharp, curved scissors remove the underlying fat. This is critical, as fat will impede vessel ingrowth and the graft will not take.

Preparation of the Skin Graft

Place the graft on the wound dermis side down. Cutting holes in the graft with an 11 blade or scissors, pie crusting, helps it to cover a larger area, but without a true mesher, one must place a lot of cuts in the graft for it to significantly expand in size (Fig. 14.3). Pie crusting allows egress of serum or blood that would prevent the graft's take. Suture from the graft to the edge of the recipient wound edge to keep the graft from displacing (Fig. 14.4). The graft can be secured with a tie-over bolster by leaving 6–8 cm lengths of suture spaced radially around the graft. These are tied over a mounded dressing of Xeroform, Vaseline, or damp gauze to stabilize the graft. Plaster splints and ex fixes are helpful for immobilization and elevation to decrease swelling and promote healing.

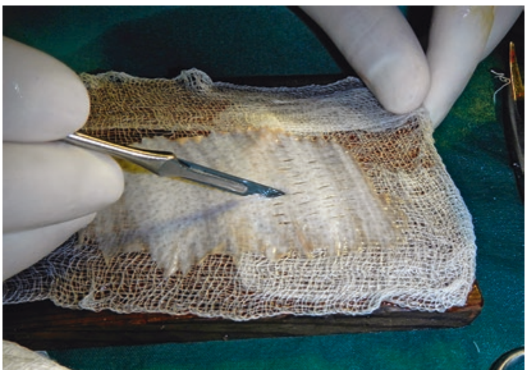

Fig. 14.3 Meshers are often unavailable. Many small cuts, made in a precise, concerted fashion will help expand the graft size. A wooden "cutting board" helps control the depth and size of the cuts

Fig. 14.4 STSG being sewn in place. Suture first from the graft then to the wound edge to stabilize the graft and prevent it from displacing

Flaps

Wounds that require flap coverage are usually those with exposed bone or tendon or are in an area where a skin graft is not sturdy enough for long-term coverage, such as a pressure sore or open fracture. A flap is vascularized tissue, usually skin, fascia, muscle, or a combination. A local flap can be created if there is sufficient uninjured tissue around the wound that can be moved into the defect. When local tissue is not available, a distant flap must be created. Initially the circulation to the flap comes from the donor tissue with gradual ingrowth of vessels from the recipient wound bed. Use of distant flaps needs to take into consideration the position of the parts and comfort for the patient to prevent joint stiffness due to immobility.

General Principles

To optimize circulation and reliability of a skin flap, heed the 3:1 rule: the flap should not be longer than three times its width. Proximally based flaps are more reliable than those based on distal circulation. Delaying the flap—whereby the flap is incised and freed from all attachments except the pedicle and then loosely sutured back in place—will improve circulation by opening vessels within it. Wait 2–3 weeks to move the tissue into the defect. Close the flap defect with an STSG when a primary closure would result in undue tension.

Local Flaps

V-Y Advancement Skin Flap

A V-Y advancement skin flap is useful for covering ischial pressure sores and other wounds with lax surrounding tissues. They are commonly used for fingertip injuries when secondary healing is impractical. This flap counts on the deep tissue underlying the flap and the laxity of the surrounding tissues for its blood supply.

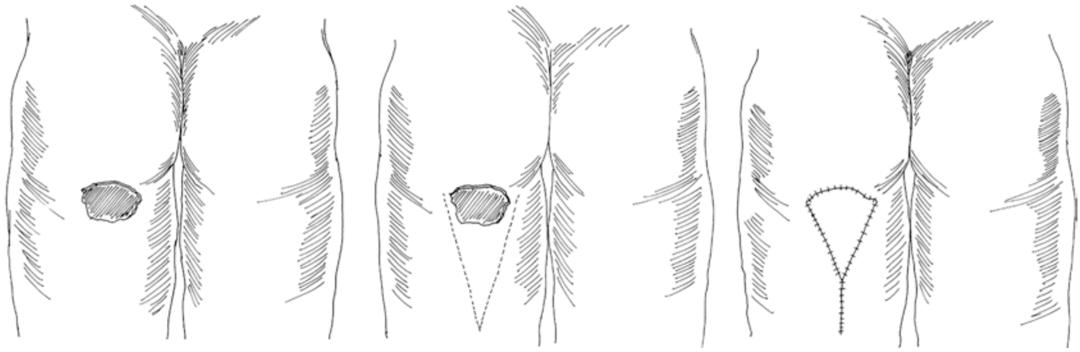

Fig. 14.5 Line drawing of V-Y plasty flap for covering an ischial pressure sore. (Courtesy of Nadine Semer)

Procedure (Fig. 14.5)

1. Determine the site where the surrounding skin laxity is greatest.
2. Draw out the flap by marking the open part of the V at the widest edge of the wound, tapering gradually to a point.
3. Incise the skin edges through the subcutaneous tissue down to, but not into, the underlying fascia and muscle. The flap remains attached to the deep tissues.
4. Advance the flap into the wound defect.
5. Close the defect at the narrow point of the V, creating the vertical or tail component of the Y.
6. Suture the flap under no tension. It is better to have small gaps in the skin closure, which will eventually heal, than a tight closure, and have part of the flap necrose.

Gastrocnemius Muscle Flap

A gastrocnemius muscle flap can cover exposed bone or a fracture site involving the proximal 1/3 of the tibia or the knee. It is best to do this flap within the first couple of weeks after injury before chronic inflammation in the surrounding tissues makes it difficult to mobilize the muscle. The best strategy is to move muscle alone and place an STSG over it.

The gastrocnemius muscle is the most superficial muscle of the posterior compartment of the leg. It originates from the distal femur and joins the underlying soleus muscle forming the Achilles tendon. The blood supply is a single dominant vessel that enters the muscle proximally, near the posterior knee joint. The medial muscle is most often used because it is larger and has a better arc of rotation to reach the front of the tibia.

Procedure

1. If available, use a tourniquet for the dissection.
2. Remove all dead bone and other tissue. If in doubt, debride, dress, and return in 3–5 days.
3. Extend the open wound onto the medial calf to visualize the underlying muscle. Try not to leave intact tight skin bridges that can compress and necrose the muscle as in (Fig. 14.6c).
4. Separate the gastrocnemius muscle from the overlying skin and underlying soleus muscle. This can often be done with blunt dissection.
5. In the back of the calf, the two heads of the muscle come together at the central raphe, identified by the presence of the sural nerve. Divide the muscle along the raphe, transferring 1/2 of the muscle, and divide the muscle distally from the Achilles tendon.
6. Bring the muscle around to the defect. Release proximal attachments as needed for length. Usually the origin of the muscle does not require division, but if additional length is required for the muscle to rotate into the defect, divide the origin with care to protect its vascular supply.
7. Once the muscle is freed, release the tourniquet and control bleeding.

8. The muscle should look pink when the tourniquet is removed. If it remains dark or does not bleed, the vascular pedicle has been injured, and the muscle is unusable.
9. Suture the muscle loosely to the wound edges. If it cannot completely cover the wound, cover the important structures for which the flap is being made. An STSG can cover the soft tissues now or at a second procedure in 4–5 days.
10. Be sure the muscle is still pink after being sutured in place and is under no tension.
11. Close the skin extension primarily if possible and place a suction or Penrose drain in the defect.
12. Place the leg in a posterior above-knee splint with the ankle at 90°, with instructions for bed rest and gentle elevation.

Keep the leg immobilized and elevated for at least 2 weeks after the operation. If the skin graft and all wounds look healthy at that time, the patient can dangle the leg, for a few minutes at a time, gradually increasing over the next few weeks. Gently wrap the leg with a compression bandage for several months to prevent swelling.

Soleus Muscle Flap

The soleus muscle flap is most useful for wounds in the middle of the tibia. This muscle has a segmental blood supply making it less reliable than the gastrocnemius flap. It is also deeper than the gastrocnemius, lying against the tibia, and can be severely damaged in injuries that particularly need coverage, such as open, comminuted, mid-

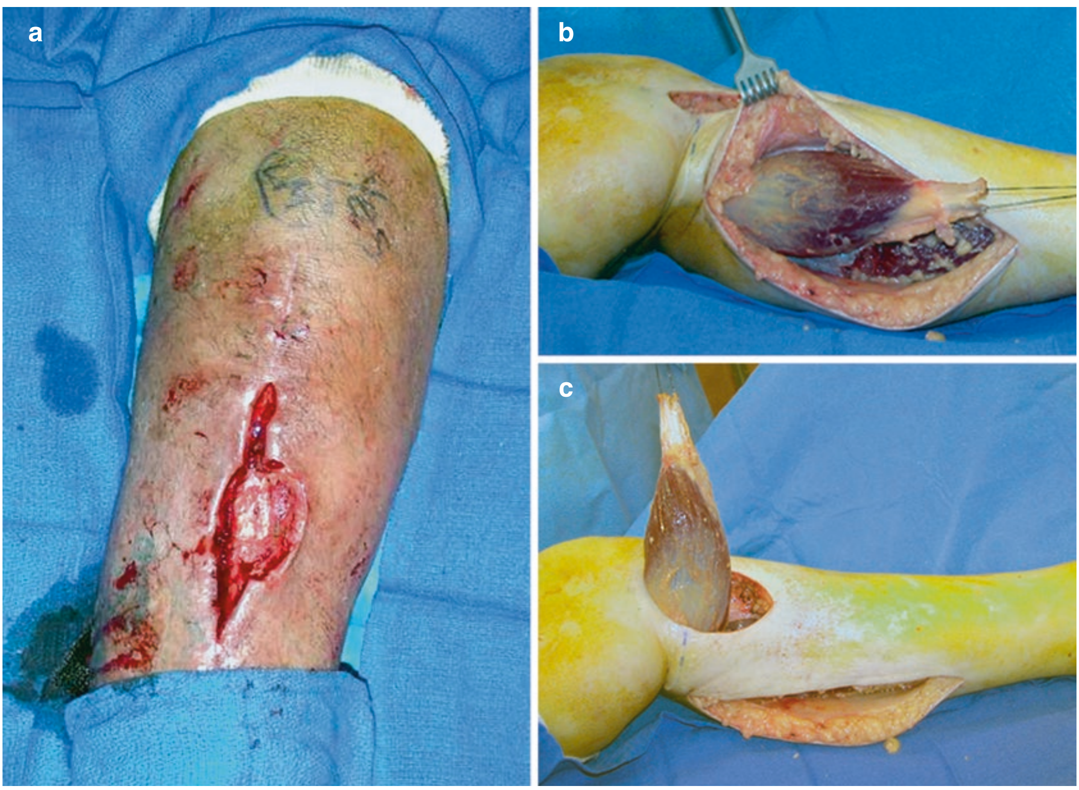

Fig. 14.6 (**a**) An exposed proximal tibia from a shrapnel wound that has been debrided. (**b**) The medial gastrocnemius is harvested through a separate incision. (**c**) The muscle has been tunneled under the fasciocutaneous bridge to cover the exposed bone and will be sutured in place. Definitive closure is with an STSG immediately or at 5–7 days

shaft tibial fractures. The dominant vessels enter the soleus muscle in the proximal half of the muscle with smaller vessels feeding the muscle distally.

There may be cases where the need for tibial coverage exceeds the possibility of either a gastrocnemius or a soleus. When half of each muscle is used, both gastrocnemius and soleus can be used together without jeopardizing the function of ankle plantar flexion.

Procedure

1. If available, use a tourniquet for the dissection.
2. Be sure the wound is adequately debrided and that all the dead tissue and bone are removed.
3. Extend the wound onto the medial calf skin to visualize the underlying muscles. Try not to leave skin bridges, which will compress and diminish the circulation, necrosing the muscle. Identify the gastrocnemius muscle, the most superficial muscle in the calf. The plane of dissection is between the gastrocnemius muscle and the underlying soleus muscle. This can usually be done bluntly or with electrocautery when in the correct plane. Do not separate the gastrocnemius muscle from the skin. Any crossing vessels should be tied off.
4. Bluntly separate the soleus muscle from the muscles of the deep posterior compartment of the leg, taking care to avoid damage to the perforator vessels coming from the posterior tibial artery.
5. Release the tourniquet and control bleeding.
6. Determine whether the vascular supply to the muscle is sufficient to supply the flap by placing a small non-crushing clamp across the vessels that you plan to divide, before the division. If the muscle turns purple when the clamp is placed, the blood vessel you are basing the flap on will *not* supply enough circulation to the flap.
7. Divide the vessels not needed for flap viability.
8. Divide the muscle. If the flap is proximally based, divide the muscle from the Achilles tendon; if the flap is distally based, divide the muscle's origin. Bring the muscle to the exposed fracture or wound site.
9. Suture the muscle loosely to the wound edges. If the muscle cannot completely cover the wound, have it cover the exposed bone or tendons. Soft tissues can be covered with an STSG.
10. Place suction or Penrose drains under the muscle flap and from the donor area.
11. Place an STSG over the muscle at this time or in 2–5 days.
12. Place the leg in an above-knee splint, incorporating the ankle at 90°, and keep the leg gently elevated.

Post-op: Same as for gastrocnemius flap. http://www.vidinfo.org/video/71640555/gastroconemius-soleus-flap.

Fasciocutaneous Flap

A fasciocutaneous flap (Fig. 14.7) provides safe, simple coverage, requiring no special equipment or expertise. Using the 3:1 length to width ratio, the skin, subcutaneous tissue, and deep fascia are raised from the adjacent tissue and rotated to cover the defect. This random flap relies on the rich vascular network of the deep fascia.

Procedure

1. The flap is outlined allowing sufficient length to rotate it into position.
2. Starting at the end—distal if the flap is proximally based—cut through the skin, subcutaneous, and deep fascia, keeping the three layers the same length.
3. Elevate the flap by dissecting in the subfascial plane.
4. Using fine sutures secure the fascia to the subcutaneous to prevent shearing of the layers.
5. The flap can be inset into the wound, or if there is any question about its viability, it can be returned and sutured to its bed and inset in 2–3 weeks.
6. Apply STSG to the donor bed and other parts of the wound uncovered by the flap at the time of inset or at a later date. A drain is advised.

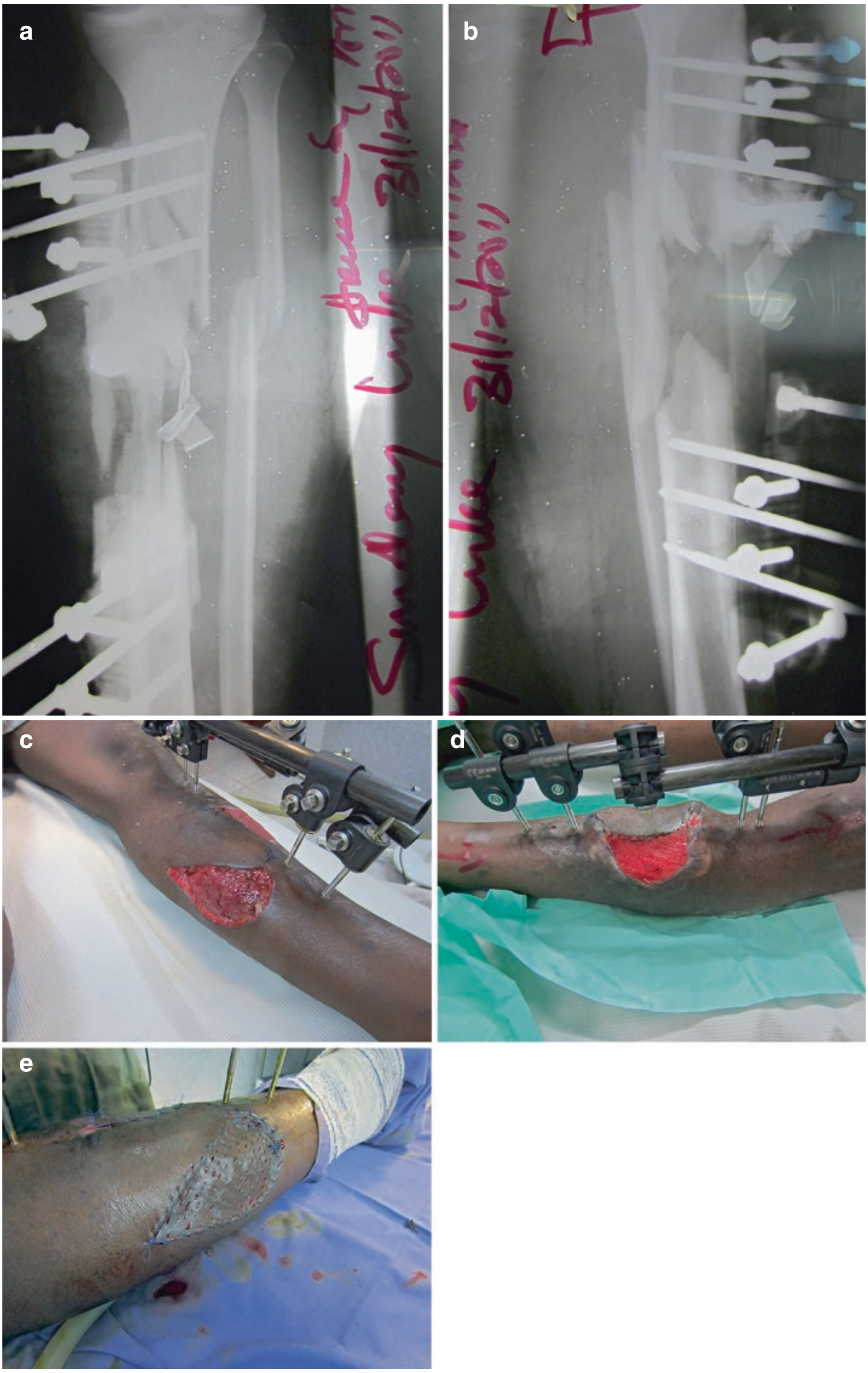

Fig. 14.7 (**a**, **b**) X-rays of a comminuted Gustilo IIIB tib fib fracture with anterior bone loss. (**c**, **d**) A fasciocutaneous flap has been mobilized from the well-muscled lateral side to cover the bone. Notice exposed lateral (**c**) and medial (**d**) soft tissues uncovered by the flap. (**e**) Five days later medial and lateral STSGs are placed

Even with an ex fix, the addition of a plaster back slab will help to prevent motion of the muscles controlling the ankle and foot and equinus contracture.

Distant Flaps

Flaps to cover upper extremity wounds can be taken from the chest or abdomen. They require preop planning to map out a position that allows mobilization of the shoulder, the joints adjacent to the wound, and edema control. Initial postoperative immobilization must be secure enough to prevent the flap from kinking or pulling free when the patient awakens from anesthesia. Depending on the wound, these flaps can be done under general, regional, or local anesthesia (Fig. 14.8).

Procedure

1. Ask the awake patient to position the injured hand over the chest or abdomen in the most comfortable position. Stay away from breast tissue.
2. Mark this area. The flap should be drawn so that the hand can be comfortably attached and not kink the pedicle. Usually base the pedicle inferiorly, but any orientation can work. Avoid scars from previous injuries.

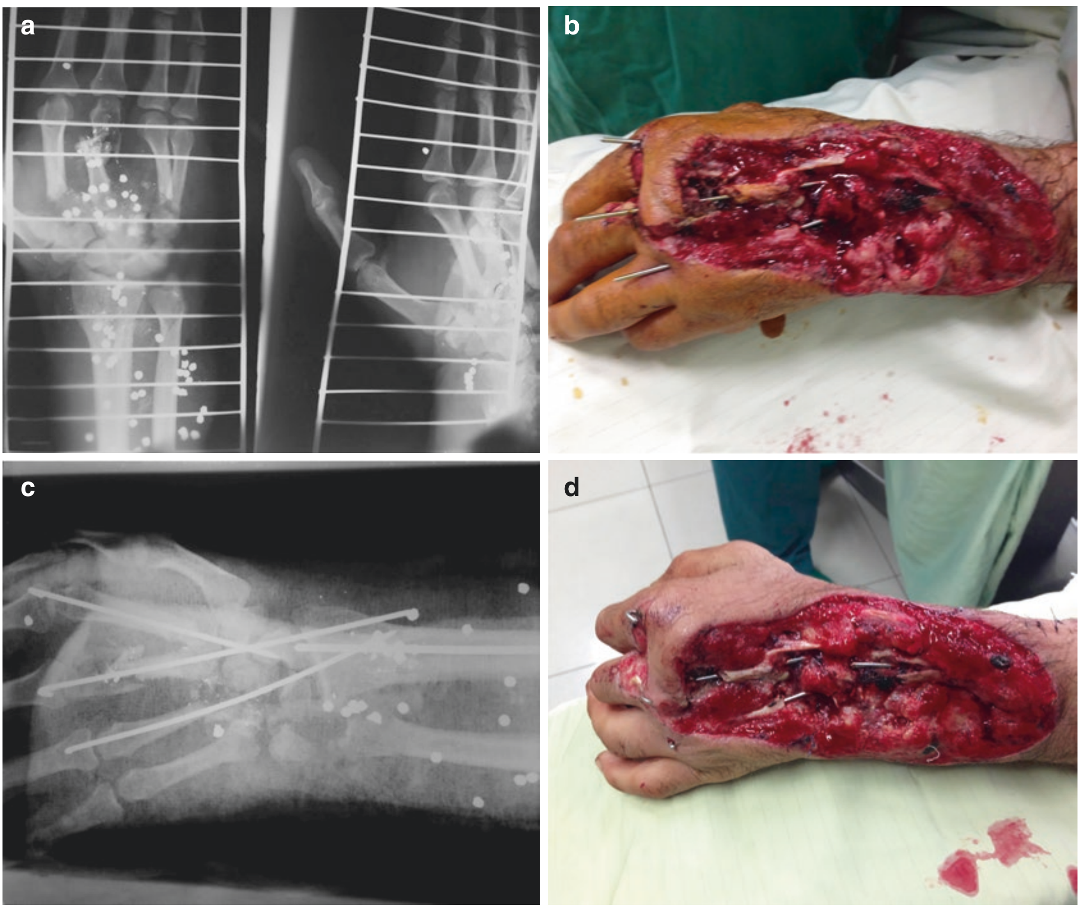

Fig. 14.8 (**a**) Presenting x-rays of hunting gun injury of the left hand with loss of dorsal soft tissues and ext tendons and multiple fractures. (**b**) Wound after debridement and pinning. (**c**) X-ray after alignment pinning MCs and distal radius. (**d**) Wound at time of abdominal flap. (**e**) Flap in place. (**f**) Six weeks after injury, flap detached and ready for suture removal

Fig. 14.8 (continued)

3. Design the flap so it is slightly larger than the defect.
4. Incise the skin, subcutaneous tissue, and underlying fascia. Do not incise muscle. The fascia contributes to the blood supply to the flap so keep it with the flap whenever possible.
5. Elevate the flap off the deep underlying tissues.
6. Loosely suture the three free sides of the flap in place. Leave small gaps if necessary to prevent a tight closure. Place a drain.
7. If unable to primarily close the donor site, place an STSG or allow it to heal secondarily.
8. Be sure you can see the flap through your dressings, so its circulation can be evaluated.

Groin Flap

See Fig. 14.9.

https://www.youtube.com/watch?v=UZAk_tLAuU0 step by step video of groin flap.

Flaps for Coverage of Distal Tibia/ Ankle

Septocutaneous or Perforator Flap

Septocutaneous or perforator flaps from the posterior tibial or peroneal arteries have expanded the armamentarium for nonspecialist surgeons to cover soft tissue defects of the distal tibia and ankle. In the face of trauma, these flaps require only a handheld Doppler probe to map out the path, distribution, and robustness of perforator arteries to fashion flaps not limited to the 1:3 rule. They can be pedicled, though are often islanded and can be rotated up to 180°. Advantages are morbidity limited to one extremity, as opposed to cross-leg flaps, and no need for microsurgical instruments or the skills for free flaps. As with all local flaps raised near the zone of injury, one must take into account degloved and crush components that affect donor viability [1]. In trauma situations with bone loss or instability that will require multiple procedures and trips to the operating room,

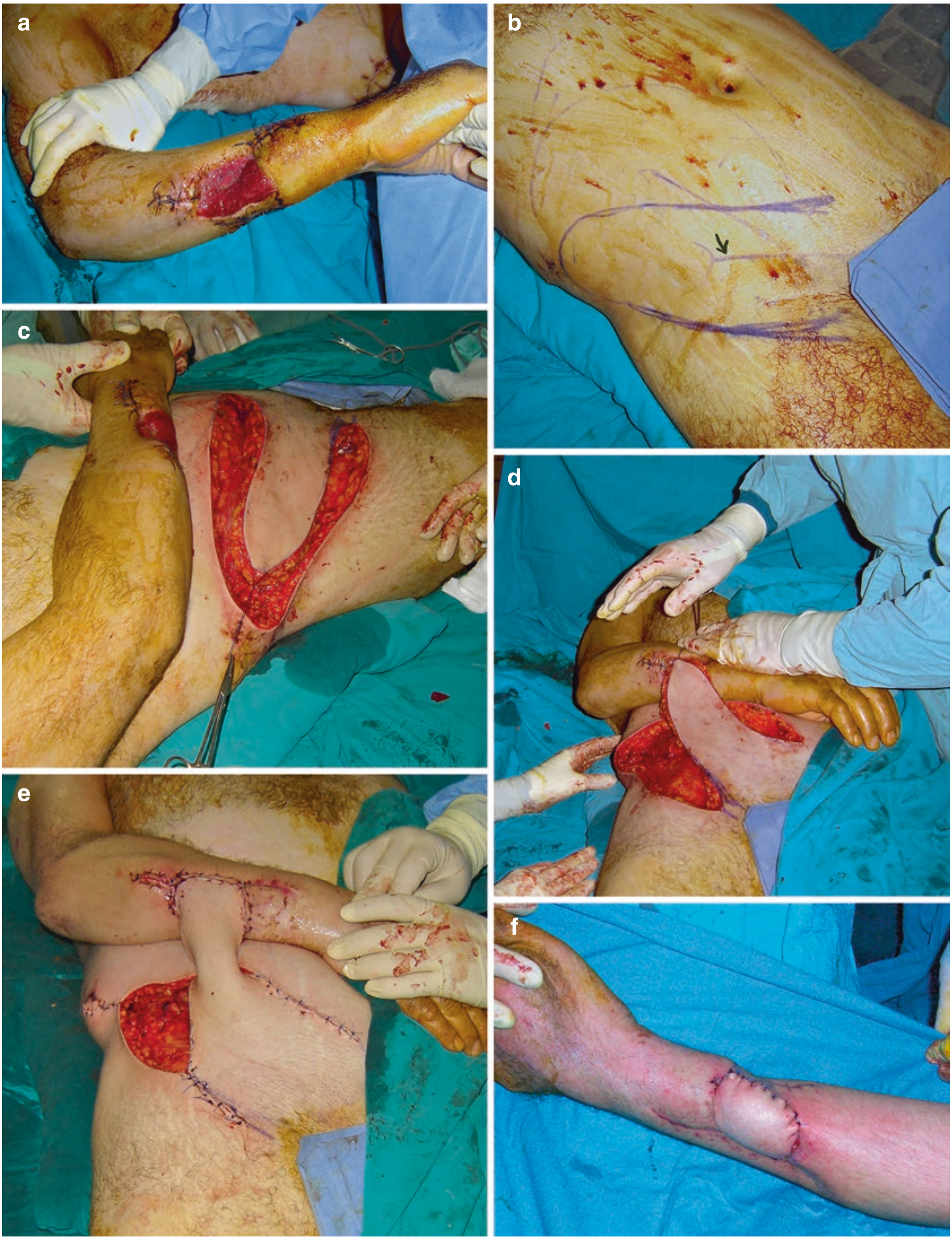

Fig. 14.9 (**a**) A shrapnel wound over the ulnar border of the right forearm, with exposed ulna. (**b**) Drawing of proposed flap, based on the superficial circumflex iliac artery (*arrow*). (**c**) Flap is elevated and (**d**) rotated to cover the defect. (**e**) The flap is tubed and sutured to the recipient site. The donor site is partially closed primarily; the rest will be covered with STSG. (**f**) Appearance after the flap was detached at 3 weeks

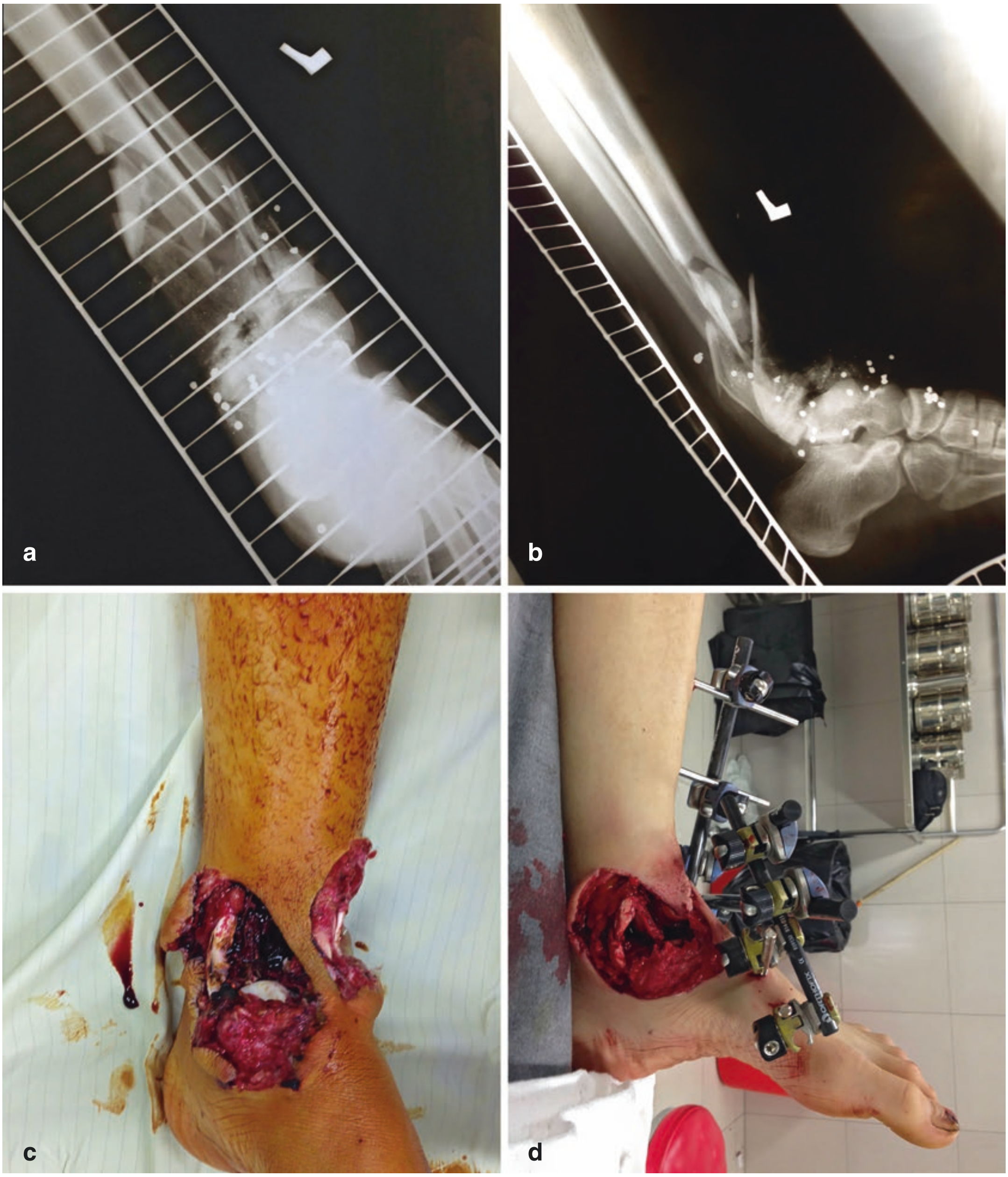

Fig. 14.10 (**a**, **b**) Initial x-rays of a 14-year-old male with hunting gun injury. Distal tibia and proximal talus and parts of fibula gone with medial and lateral soft tissue loss. (**c**) Appearance in OR 4 days after initial debridement, showing narrow full-thickness anterior bridge of soft tissue with extensive medial defect. (**d**) Ex fix applied laterally to not interfere with future medial flap. No attempt was made to preserve full length. (**e**) Posterior tibial pedicled perforator flap inset. (**f**) STSG and flap 1 month after injury at time of removal of ex fix. (**g**, **h**) Ap-lat ankle x-rays 6 months after calcaneal-tibial SIGN nail and bone graft. Tibial-talar fusion solid though sub talar joint appears to have movement. The patient walks without aids

Fig. 14.10 (continued)

early Doppler evaluation and assessment for ex fix placement as well as alternative plans are important (Fig. 14.10).

https://www.youtube.com/watch?v=eFaclQZeDBU and https://www.youtube.com/watch?v=LyJ9rNrVCPo.

Cross-Leg Flap

This is a useful fasciocutaneous flap for complex wounds or fractures involving the distal third of the calf, ankle, or foot with exposed tendons or bone. The patient's legs must be immobilized together, in a relatively awkward position for 3–4 weeks, which can result in significant and permanent hip stiffness in adults, making it more useful in patients younger than ~25 years (Fig. 14.11).

Procedure

1. With the patient awake, determine the optimal leg position so that a flap of tissue taken from the non-injured posteromedial calf will lie easily over the defect with the least discomfort.
2. Draw the flap, slightly larger than the defect, with the pedicle based superiorly.
3. Incise the skin, subcutaneous tissue, and fascia as described above for fasciocutaneous flap.
4. Loosely suture the three free sides of the flap in place and place a drain.

Fig. 14.11 Cross-leg flap. (**a**) A fasciocutaneous flap following the 3:1 length to width rule is raised. (**b**) The base of the flap is tubed to improve maneuverability. (**c**) Cancellous bone chips are placed in the distal tibial defect before the flap is set. (**d**) Appearance 2 weeks after flap inset. Note: an external fixator or plaster is necessary to maintain the legs in position

5. Cover the donor site with STSG.
6. Immobilize the legs together. In children use a plaster hip spica cast with a bar connecting the legs. Window the plaster over the flap, so it can be observed and cleaned. In adults, the plaster can often be loosened or removed after a few days, but children will need to remain immobilized. An external fixator will hold the position and also allow good access to the wounds.

General post-op care for all flaps involves cleaning the suture lines with saline or gentle soap and water. Apply antibiotic ointment if available.

Another flap for distal leg coverage is the reverse sural artery flap. It is useful for heel and lateral hindfoot coverage (https://vimeo.com/147850602 and https://www.vumedi.com/video/reverse-sural-flap-for-distal-one-third-tibial-wounds-foot-and-ankle-wounds).

Postoperative Troubleshooting

If any of the abovementioned flaps become swollen or bluish within a few hours of the operation, the circulation has been compromised—usually a venous, outflow problem.

1. Check positioning, especially if a distant flap, make sure the pedicle is not kinked.
2. Loosen the dressings.
3. Remove a few sutures.
4. Be sure no hematoma lies under the flap.
5. Be sure the patient is warm and has adequate pain control.

Flap division for distant flaps can usually be done ~4 weeks after the initial flap creation. If occlusion of the pedicle with fingers or an atraumatic clamp for 30s creates pallor or loss of capillary refill, the flap should not be completely divided at that time.

Scar Modalities

Complete wound healing and scar maturation take many months. Prevention of scar contracture is critical for optimal outcomes, especially when dealing with hand injuries. Simple scar massage is highly effective and can be done by the patient or family or a traditional healer. Two to three times each day, gentle massage to the scar will gradually soften the tissues and improve range of motion. Moisturizing lotions are useful, and rural communities have local plant products that can be used. Massage needs to continue for months after the injury to limit tightness and contracture that can lead to decreased mobility and disability.

Tight, immobile scars unfortunately are common in patients who sustain deep burns to the hand, antecubital fossa, axilla, and neck. The best treatment is prevention by splinting, range of motion exercises, early skin grafting, and scar modalities. However, when contractures are present, morbidity can be extreme. Z-plasty is a technique whereby the scar tissue is rearranged to lengthen the scar and improve mobility. Due to the geometry of creating the Z-plasty flaps, the gain in length is coupled with a loss of width, which can be problematic. In general, a more reliable way to treat scar contractures is to cut into or resect the tight scar to allow full range of motion at the joint and cover the resultant defect with a full-thickness skin graft. Be sure to use splints to immobilize the area and promote graft "take" as well as prevent contracture recurrence. For fingers K-wires will keep the fingers in proper position; for children casting may also be necessary.

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15 HIV and Orthopedic Surgery

William James Harrison

Introduction

Visiting clinicians need to be aware of the special considerations for orthopedic surgical care in patients with HIV/AIDS and the appropriate measures to prevent and treat occupational exposures. The human immunodeficiency virus (HIV) is a retrovirus that hides within the RNA of host cells. It targets T-helper (CD4) cells, depleting them in number and effectiveness, reducing host defenses and surveillance, and increasing the risk of infections and certain tumors.

There are an estimated 36.7 million HIV-positive individuals worldwide, approximately two thirds, 25.5 million, live in sub-Saharan Africa [1] with a higher prevalence in southern Africa. Trauma patients have a higher seroprevalence rate compared with national averages [2]. The South and Southeast Asian region have approximately 5.1 million persons infected. New diagnoses have decreased globally since 2001 to 1.8 million in 2016, and the annual number of deaths has fallen from 1.9 million in 2005 to 1 million in 2016.

Combination drug therapy, highly active antiretroviral therapy (HAART), has become increasingly available in resource-poor settings since 2003. HAART is effective in prolonging life, restoring activity levels, preventing maternal-fetal transmission, reducing infectivity, and generally improving the quality of life. Previously indications for HAART included (1) progression to AIDS (Pneumocystis carinii pneumonia), (2) CD4 count of ≤250 cells/mm, and (3) prevention of maternal-fetal transmission, but many countries now treat all infected persons. These drugs are associated with significant side effects, some of which affect the musculoskeletal system.

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Relevant Issues for Orthopedics and Traumatology

Several common associations between musculoskeletal diseases and HIV have been identified. Arthropathies are seen in adults and children—most commonly Reiter's syndrome and psoriatic arthropathy—and the clinician must differentiate inflammatory arthropathy from acute septic arthritis. While septic arthritis in association with HIV is unusual until immunity has been substantially reduced, inflammatory joint problems can occur at any stage.

Avascular necrosis (AVN), especially of the femoral head, occurs with HIV, though the pathogenesis remains unclear. AVN has been identified in patients on protease inhibitors, but some patients are symptomatic before starting HAART [3]. Recently, osteoporosis associated with treatment has received considerable atten-

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tion in the Western literature, particularly after prolonged use of HAART. In sub-Saharan Africa, this entity is not well described, perhaps because the use of HAART has been limited until recently.

Infection with HIV/AIDS must always be suspected when adults are diagnosed with septic arthritis. The association in children is not as strong [4]. Other conditions seen with frequency include other musculoskeletal infections (tuberculosis [5] osteomyelitis, and pyomyositis) and malignancies (Kaposi's sarcoma, non-Hodgkin's lymphoma). The association between HIV and TB is quite common and of particular interest to the orthopedic surgeon, as tuberculous musculoskeletal infections are much more frequent in HIV-infected patients. Fungal bone and joint infections should be considered in atypical cases. Histology may be the easiest way to make diagnoses of fungal and tuberculous infections.

Those providing surgical care to patients with HIV/AIDS should be aware of how outcomes can be influenced, and misconceptions are common. The optimal method of fracture reduction and stabilization depends on the time of presentation, severity of soft tissue and other injuries, and local resources. There is no increased risk of wound infection following internal fixation of closed fractures in patients with HIV/AIDS if surgical conditions are sterile [2, 6]. There is no need for prolonged antibiotic coverage; however, the risk of wound infection following an open fracture is greater in HIV patients [7, 8], and in the author's experience, this risk can be reduced by aggressive early debridement, skeletal stabilization, early soft tissue reconstruction, and negative-pressure wound therapy. Pin-track infections following external fixation are more common but are usually manageable with simple antibiotics [9].

While some reports suggest fracture union rates are lower in patients with HIV/AIDS due to an impaired inflammatory response [7, 8], our experience has not supported this [10]. The impact of HAART on bone union is currently under investigation, and delayed fracture union may be an association although its clinical significance has not yet been proved. Delayed sepsis of an existing implant has been described, but it is unclear whether this represents reactivation of latent infection or a recent hematogenous seeding. In our experience this is an uncommon complication, and it is unnecessary to routinely remove implants. Patients with HIV/AIDS may be candidates for joint replacement, particularly total hip arthroplasty after osteonecrosis or trauma. The limited information shows that patients have satisfactory results at early and medium-term follow-up with both uncemented and cemented implants; however, late sepsis remains a concern [11, 12].

Occupational Hazards

The risk of seroconversion after an occupational exposure depends on the size of inoculation (higher in open injuries, hollow needles), the patient's viral load (highest at initial seroconversion and in late, untreated disease), and early access to postexposure prophylaxis. Published information indicates that the overall risk after exposure is approximately 0.3%, and this can be reduced up to tenfold by postexposure prophylaxis (PEP) [13]. HAART reduces the patient's viral load dramatically, reducing the patient infectivity to health providers. The risk from exposure through local contact with mucous membranes is less than from a needle stick or bone spike puncture.

Prevention is better than cure, and clinical staff must make every effort to reduce their exposure to HIV. In the author's practice, preoperative screening is only used to optimize patients for surgery and occasionally to guide decision-making or inform prognosis. We prefer to view all patients as potentially infected. This awareness should also reduce the exposure risks of hepatitis B and C. In the operating room, all personnel should wear protective eye wear or face shields and double glove. Sharp instruments (scalpels, needles) should be placed in a kidney basin on a safe surface and not passed between staff. Needles are not re-sheathed but kept in the kidney dish until disposal in a sharps bin. Clear spoken communication when moving sharps may reduce accidents. The author generally favors longer wounds to give better visualization and avoids blind finger probing around sharp bony edges. Instruments are used to reduce and hold bone fragments rather than fingers. Care must be taken to avoid excessive force, and tissues should not be devitalized when gaining exposure.

A hospital policy for PEP should be in place, and all staff need to be familiar with the protocol. The injury is immediately washed with soap and water and allowed to bleed, and mucous membranes are flushed copiously with water. The clinician and patient should immediately be tested for HIV and the patient counseled regarding the event. In our experience, PEP is indicated when the patient is HIV positive and the clinician is HIV negative, although protocols vary between institutions and will evolve over time. The regime chosen depends on judged exposure risk, and treatment should be commenced as early as possible after exposure. Ideally, the results of blood tests are available within a few hours, and if not, the decision to begin PEP is based on clinical circumstances. This typically involves a 1-month course of antiretroviral therapy, though the specific regimes often change, depending on local variables. Physicians traveling to endemic regions where PEP is unavailable should consider carrying a starter pack for PEP.

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16 Anesthesia for Orthopedic Surgery in Austere Environments

Ercan Türeci, Aybike Onur Gonen, and Ahmet Temizyürek

Introduction

This chapter is written for orthopedic and general surgeons working in austere environments where the limitations of the essentials for safe anesthesia—trained professionals, appropriate drugs, and medical equipment—will likely shape surgical plans.

Preoperative Assessment

A preop assessment includes a thorough medical and surgical history, allergies, current medications, last oral intake, and a quick physical exam, focusing on airway, respiratory, and cardiopulmonary systems. In the field this information is often inaccurate due to mass casualty situations, language barriers, cultural differences, and traditional health beliefs. Drugs and anesthesia method should take into consideration these possible inaccuracies.

Estimation of body weight for adults is acceptable, but to avoid overdosing in children, use the following formula: Body weight (kg) = (Age + 4) × 2.

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Fasting

Verbal and written instructions on fasting time should be given in local and mission language, supplemented with a bedside sign (Box 16.1).

Give premedication with metoclopramide, an H_2 receptor antagonist, or proton pump inhibitor 2 hours preop or 30 min preop with a non-particulate antacid, such as 30 ml of 0.3 M sodium citrate, if fasting times cannot be assured (Table 16.1).

Box 16.1 Recommended Preop Fasting Times
Clear fluids—2 hours
Pulpy juice, breast milk—4 hours
Milk, baby formula, solid food—6 hours

Pediatric Patients

Perioperative care should be planned considering that children have:

1. Higher metabolic rates and lower respiratory reserves: beware of hypoxia.
2. Differences in drug kinetics and dynamics: be careful with the drug choices and doses.
3. Rapid heat loss: beware of hypothermia and cover the patient well, including the head.
4. Low circulatory reserve: necessitates careful blood loss monitoring and earlier resuscitation.

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Intraoperative Care

Monitoring

Continuous ECG along with pulse oximetry and blood pressure measurement every 5–10 min is essential. Temperature is especially important for children. The triad—look, listen, and feel—employs three senses for the most basic monitoring. Observe chest and abdominal movements both for airway and breathing and skin color for O_2 saturation. Listen to the heart rate and rhythm and breathing with a precordial stethoscope. Feel the skin for temperature and arterial pulse to quickly assess the circulation.

General Anesthesia and Sedation

Anesthesia with the patient breathing spontaneously is the first choice in an austere environment, even if an anesthesiologist is present. Emergency and anesthesia meds should be prepared or checked before the surgery is started to make sure they are readily available.

Table 16.1 Premedication for inducing gastric emptying

Drug	Adult	Children
Metoclopramide	10 mg IV	0.1–0.2 mg/kg IV
Famotidine	20 mg IV	0.5 mg/kg IV
Ranitidine	50 mg IV	1 mg/kg IV
Omeprazole	20 mg IV	0.5 mg/kg IV
0.3 M sodium citrate	30 ml PO	0.5 ml/kg PO

Ketamine

Ketamine acts rapidly as a general anesthetic and analgesic, creating dissociative anesthesia and is widely used in the field, with or without the addition of sedation and regional or local anesthesia (Table 16.2). It maintains cardiac output, raises the heart rate and blood pressure, causes bronchodilation, and protects laryngeal and pharyngeal reflexes by central sympathetic stimulation, making it the best option for hemodynamically unstable trauma patients. It causes hypersalivation, which can be prevented by 0.5 mg IV atropine for adults or 0.01 mg/kg for children. 0.05 mg/kg IV diazepam or midazolam premedication may alleviate the psychosensory side effects which can be an important aspect in cultures with strong local beliefs about hallucinations.

Sedation with Analgesia

Benzodiazepine and opioid combinations or low doses of ketamine are commonly used for sedation and analgesia. Drugs in increments of quarter to half doses can be repeated to maintain the desired level of sedation. Beware of respiratory depression, and use flumazenil if adequate respiratory support cannot be provided (Table 16.3).

Regional Anesthesia

Regional anesthesia includes neuraxial anesthesia, regional intravenous anesthesia (RIVA),

Table 16.2 Ketamine

Route	IM/rectal	IV	Continuous IV infusion
Dose	5–10 mg/kg	1–2 mg/kg *(adult)*	1–2 mg/kg *(adult)*
		0.5–1 mg/kg *(children)*	0.5–1 mg/kg *(children)*
Onset	5 min	1–2 min	1–2 min
Duration	20–30 min	10–15 min	Stop 15–20 min before EOS
Maintenance	5 mg/kg	0.5–1 mg/kg	2–4 mg/kg/h 30–60 mcg/kg/min
Frequency	20–30 min	15–20 min	Quick recipe
			Dilute 500 mg ketamine in 500 ml NS/RL
			Infuse 1–2 drops/kg/min
			Give 0.5–1 mg/kg intermittent boluses if necessary
			Give 0.5 mg/kg for dressing change
Notes	Ideal for children	Easy, accurate	Good management of depth of anesthesia
	Difficult to titrate		

peripheral nerve blocks (PNB), and local anesthetic (LA) infiltration. Dissociative anesthesia or sedation supported by regional anesthesia will provide sufficient pain control for most cases. Always disinfect the skin and use sterilization methods for regional anesthesia.

Table 16.4 summarizes common local anesthetics. Adding epinephrine to LA will increase duration of analgesia and maximum dose. 0.1 ml of 1 mg/ml epinephrine diluted in 20 ml LA solution to achieve a 1:200,000 solution. Some clinicians prefer a mixture of local anesthetics to achieve both rapid and long-lasting effects.

Local Anesthetic Systemic Toxicity

Local anesthetic systemic toxicity (LAST) is a legitimate worry with regional anesthesia PNB, or local infiltration, as a LA can quickly add up to toxic doses. In any mixture of LAs, toxicities are presumed to be additive, and maximum doses should be calculated accordingly.

The signs and symptoms of LAST are variable and primarily affect the central nervous or cardiovascular systems. Any sudden or unexpected changes such as light-headedness, mental status changes, incoherent speech, perioral numbness, metallic taste, visual changes, muscle twitching, tremors, seizures, hypertension, AV block, and other ECG changes should alert to possible toxicity. Hypotension, bradycardia, and asystole can also occur due to cardiac depression.

Basic precautions include using the lowest effective doses of LA, frequent suctioning of needle during injection to avoid intravascular injection, and using epinephrine (5 mcg/ml of LA) as an IV marker (Box 16.2).

Box 16.2 Treatment of LAST

Stop injection of LA, give 100% O_2
Cardiovascular and respiratory support
IV midazolam 3–10 mg for convulsions
If available, lipid emulsion therapy just in case: IV bolus of 1.5 ml/kg of 20% lipid emulsion over 1 min; followed by 15 ml/kg/hour of 20% lipid emulsion; up to five boluses if symptoms are not improving

Neuraxial Anesthesia

Spinal anesthesia is the neuraxial anesthetic choice for most pelvic and lower extremity surgeries because of its rapid onset and adequate duration.

Spinal Anesthesia

Prepare 5 mg/ml ephedrine and 1 mg/ml atropine injectors (*or diluted for children*), and set aside for emergencies. Volume load with crystalloids before procedure. Place patient lying on side or sitting with the back arched. Draw a line between the iliac crests; the interspinous space marks the

Table 16.3 Benzodiazepines and flumazenil for reversal

	Children	Adult
Diazepam	0.1–0.2 mg/kg IV	5–10 mg IV
	0.5 mg/kg rectal	
Midazolam	0.05–0.1 mg/kg IV	0.05–0.1 mg/kg
Flumazenil	0.01–0.2 mg slowly	0.2 mg slowly
	Repeat until desired effect, max. dose 0.05 mg/kg	Add 0.5 mg for desired effect, max. dose 5 mg

Table 16.4 Local anesthetics

	Onset (min)	Duration (hrs)		Toxic doses (mg/kg)		Conc. (% w/v)	Max volume (ml/kg)		Volume for 70 kg (ml)	
		Plain	Epi[a]	Plain	Epi[a]		Plain	Epi[a]	Plain	Epi[a]
Lidocaine	1–3	0.5–2	1–4	3–5	6	2%	0.25	0.3	17	21
Prilocaine	5–6	0.5–2	3–6	6	8	1%	0.6	0.8	42	56
Bupivacaine	15–30	3–4	4–8	2	2.5	0.5%	0.4	0.5	28	35
Ropivacaine	8–12	3–4	3–4	3	4	0.75%	0.4	0.53	28	37

[a]Epi: Epinephrine dose of 1:200000

L4–L5 interspace. Inject at this or level above. Infiltrate skin and subcutaneous tissues with 3–5 ml of 2% lidocaine. Introduce spinal needle (25G or 27G). When having free flow of CSF, inject 1.5–2.5 ml of 0.5% hyperbaric bupivacaine. Adding fentanyl 5–25 mcg or morphine 0.2–1 mg to LA can improve analgesia. Gravity pulls hyperbaric bupivacaine down, so immediately position the patient supine and tilted toward the operative side with head elevated 10–15°.

Tips

Spinal cord ends at L2 in adults, lower in children. Use lowest plausible interspace to avoid damage to the cord.

Hypotension: give IV fluids and, as last choice, ephedrine in increments of 3–5 ml (0.2–0.3 mg/kg for children)

Bradycardia: give 1 mg atropine (or 0.02 mg/kg for children), and place bed in reverse Trendelenburg or raise patient's head.

Headache prevention: use thinnest needle possible, and advise 24 hours bed rest, fluids (IV and PO), caffeine, and paracetamol

Bier Block: Regional Intravenous Anesthesia (RIVA)

For procedures lasting 30–45 min involving the fingers, hand, and forearm, use an upper arm double-cuffed tourniquet or two tourniquets. Place a cannula on the back of the hand. Exsanguinate the forearm with an Esmarch bandage, and raise tourniquet to 100 mmHg above systolic pressure. Inflate the proximal cuff and inject the LA. For adults: inject 50 ml of 0.5% lidocaine without epinephrine. Inflate the distal cuff then deflate the proximal cuff. Never use bupivacaine due to intravenous cardiac toxicity. The LA will return to circulation on release of the tourniquet. Check for LAST symptoms after releasing tourniquet.

Peripheral Nerve Blocks

Peripheral nerve blocks (PNB) provide adequate pain relief for surgical anesthesia as well as postoperative analgesia. Always keep LAST in mind, and watch for compartment syndrome as PNB can mask its symptoms. Stop local anesthetic injection if an abnormal resistance is felt or patient reports immediate paresthesia, as this may suggest intraneural injection.

Axillary Brachial Plexus Block

Landmarks: Find the axillary artery high in the axilla.

Technique: Use 4–5 cm long needle aimed toward and just above and then behind the artery. Inject 30–40 ml 1–1.5% prilocaine or lidocaine or 0.375% bupivacaine. Epi 1/200,000 could be added.

Wrist Block (Fig. 16.1)

Ulnar nerve—Inject 3–5 ml LA under the flexor carpi ulnaris tendon proximal to styloid after aspiration and another 2–3 ml subcutaneously to block cutaneous branches innervating hypothenar area. *Median nerve*—2 cm proximal to wrist crease inject 3–5 ml LA between the flexor carpi radialis and palmaris longus tendons. *Radial nerve*—2 cm proximal to radial styloid and lateral to the radial pulse inject 5 ml of LA. Advance needle laterally and dorsally toward anatomic snuffbox and inject 3–5 ml of LA.

Never use LA *c*ontaining epinephrine distal to the wrist or ankle.

Digital Nerve (Ring) Block

Insert a 25G needle from the dorsolateral base of the finger and infiltrate subcutaneous tissue with LA before advancing needle past the phalanx volarly until the needle tip is palpable without penetrating the skin. Inject 1 ml of LA and 1 ml more while withdrawing the needle. Repeat for other digital nerve.

Ankle block—posterior tibial, deep peroneal, superficial peroneal, and sural nerves off the sciatic nerve and the saphenous off femoral nerve (Fig. 16.2).

Place patient supine with lower leg supported over a pillow to free the ankle. Start with the two

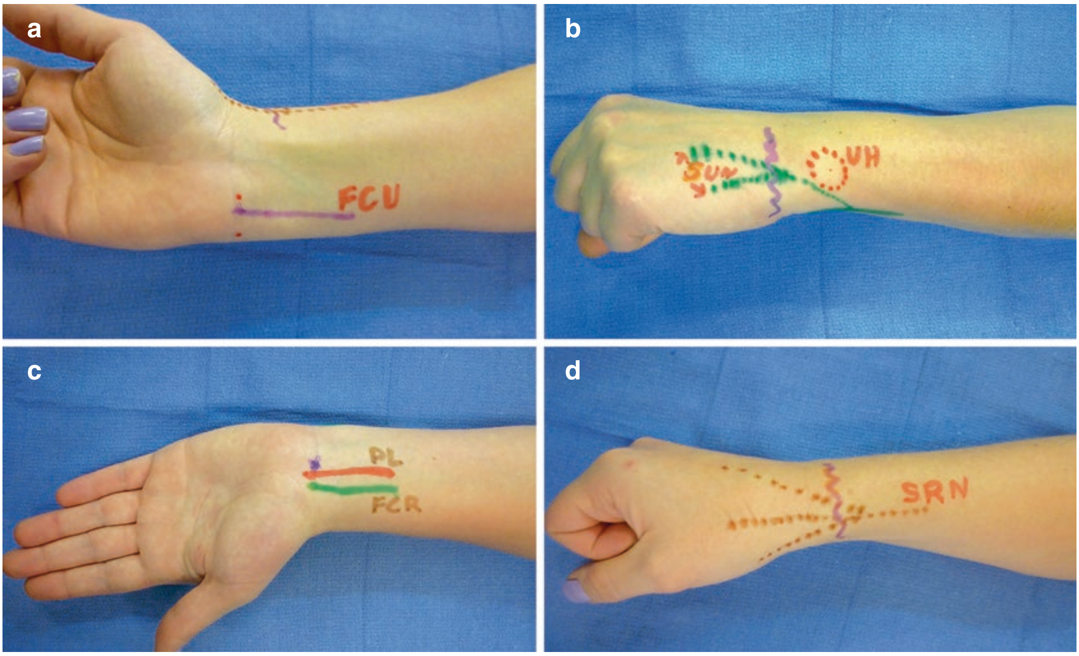

Fig. 16.1 Wrist block. (**a**) The ulnar nerve lies beneath the flexor carpi ulnaris (*FCU*) tendon and is reached by inserting a needle under the tendon just proximal to its carpal insertion. (**b**) The sensory branch of the ulnar nerve (*SUN*) is anesthetized with a "fan" or "field" subcutaneous block on the dorso-ulnar side of the wrist (*purple wavy line*), just distal to the ulnar head (*UH*). (**c**) The median nerve usually lies between palmaris longus (*PL*) and flexor carpi radialis (*FCR*) tendons and can be reached from either side of the PL tendon. (**d**) The sensory branch of the radial nerve (*SRN*) emerges subcutaneously just dorsal to the tip of the radial styloid and is addressed with a transverse field block (*purple wavy line*)

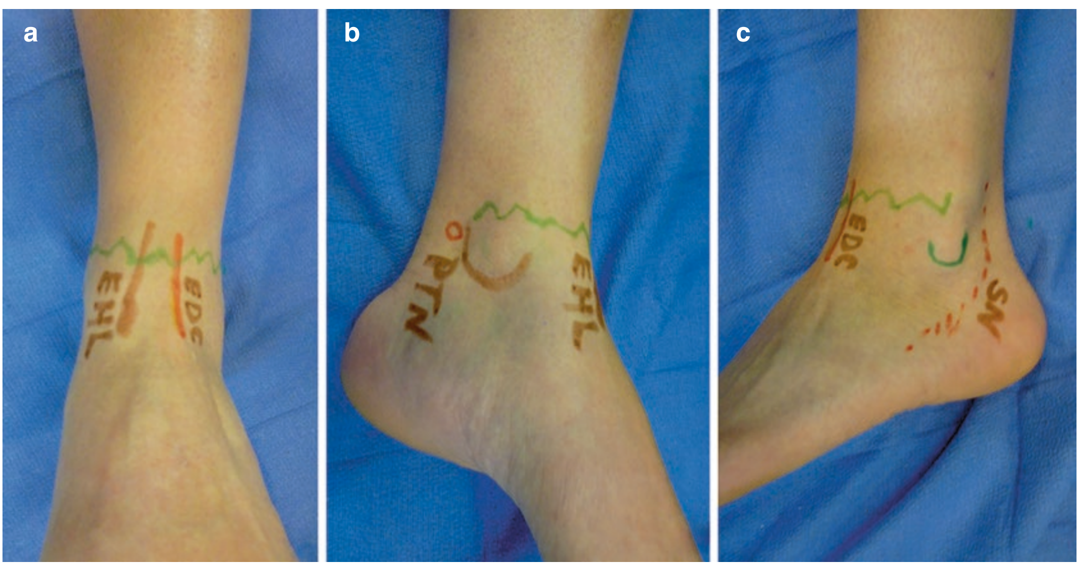

Fig. 16.2 Ankle block. (**a**) A "ringlike" field block can be done subcutaneously (*green wavy line*), blocking the saphenous nerve anterior to the medial malleolus and the superficial peroneal nerve lateral to the extensor digitorum communis (*EDC*) tendon. The deep peroneal nerve is blocked in the groove between extensor hallucis longus (*EHL*) and *EDC* tendons. (**b**) The posterior tibialis nerve (*PTN*) is blocked approximately 1 cm above and behind the tip of the medial malleolus. (**c**) The sural nerve (*SN*) is blocked at the midpoint between the Achilles tendon border and the tip of the lateral malleolus. The ring block should be continued circumferentially

deep nerves, as subcutaneous bulging from the superficial blocks can distort the anatomy. Palpate the *posterior tibial artery* behind the medial malleolus. Insert needle posterior to the artery until the malleolus is contacted. Withdraw slightly and inject 3–5 ml LA. Palpate dorsalis pedis pulse, insert the needle lateral to the artery until bone is contacted, withdraw slightly, and inject 2–4 ml of LA around the *deep peroneal nerve*. Draw a circumferential line around the ankle, connecting the superior borders of medial and lateral malleoli. Infiltrate subcutaneous tissue under anterior half of line with 10 ml LA to *block saphenous and superficial peroneal nerves*. Infiltrate subcutaneous tissue and fascia below the posterior half with 5 ml of LA for *sural nerve block*.

Fluid Management

The main goals of intraoperative fluid therapy are to provide baseline fluid requirements and replace fluid deficit due to fasting and additional volume loss during the operation.

Crystalloids are the primary choice of intravenous fluids. Clinical guidelines do not favor one intravenous fluid over another except head trauma patients, who should receive isotonic fluids and small children on prolonged fasts and who need 0.45% NaCl with 5% dextrose to avoid hypoglycemia. Caution with high volumes of 0.9% NaCl, as it may cause hyperchloremic acidosis (Table 16.5).

In the absence of a dosimeter, the rate can be calculated by drop count per minute. Usually 15–20 drops are equal to 1 ml. (Check the information in the sets package.)

Table 16.5 Adult and pediatric IV fluid management

IV fluids for adults	IV fluids for children
40 ml + 1 ml/kg per hour	0–10 kg: 4 ml/kg per hour,
Add 4 ml/kg for mild, 6 ml/kg form moderate and 8 ml/kg for severe trauma per hour	10–20 kg: 20 ml + 2 ml/kg per hour,
	>20 kg: 40 ml + 1 ml/kg per hour,
	Consider 5% dextrose as a part of fluid regimen

Blood Loss and Transfusions

Blood is used for the lifesaving situations in the field. Warm/fresh whole blood transfusion is usually the best option as it is easiest to provide.

In the absence of a lab, compatibility can be tested by mixing a small amount of donor and recipient blood over a nonreactive surface and observing agglutination. Grainy or clumpy mixes indicate unmatched blood.

Take care: Trauma patients often arrive in surgery in a hypovolemic status due to hemorrhage. Blood loss at surgery can cause further hypovolemia.

Blood loss over calculated allowable blood loss (ABL) should warrant transfusion, especially if signs and symptoms of class III or IV hemorrhagic shock are present (Table 16.6). Calculate ABL with the following formula: Blood volume × $(Hct_{initial} - Hct_{final})/Hct_{initial}$. Blood volume is estimated from ideal body weight: 80 ml/kg for infants, 75 ml/kg for men, and 65 ml/kg for women.

Tranexamic Acid (TXA)

Tranexamic acid can improve survival in injuries with severe hemorrhage. Give 1 g over 10 min within 3 hours of injury, followed by 1 g IV infusion over 8 hours. For children give 15 mg/kg with the same regimen. Benefits of TXA seem to disappear 3 hours after the initial injury.

Postoperative Care

Due to lack of a recovery room or intensive care unit and shortage of properly trained healthcare professionals, patients should be fully awake and spontaneously breathing before leaving the operating suite.

Post-op orders must be written and include:

Monitoring and follow-up
Supportive treatments: O_2 and IV fluids
Antibiotics
Pain treatment

Table 16.6 Classification of hemorrhagic shock

	Class I	Class II	Class III	Class IV
Blood loss (ml)	<750	750–1500	1500–2000	>2000
Blood loss (%)	15	15–30	30–40	>40
Heart rate (min.)	<100	100–120	120–140	>140
	Full and bounding	Full	Weak	Thready
Systolic blood pressure (mmHg)	120	90–120	<90	<60
	Normal	Radial felt	Radial not felt	Carotid not felt
Pulse pressure	Normal	Narrowed	Greatly decreased	Absent
Capillary refill	Normal	Delayed	Delayed	Absent
Respiratory rate (min)	14–20	20–30	>30	>35
	Normal	Mild tachypnea	Marked tachypnea	Marked tachypnea
Urine output (ml/hr)	>30	20–30	5–20	Negligible
Mental status	Lucid/thirsty/slightly anxious	Anxious/frightened/ irritable	Hostile/irritable/ confused	Confused/ lethargic
				Unresponsive
Base deficit	0 to −2 mEq/L	–2 to −6 mEq/L	–6 to –10 mEq/L	<–10 mEq/L

Resuming oral intake
Bed position

Post-op Analgesia

Postoperative pain and a heightened stress response are linked to poor outcomes and increased morbidity. Pain should be regularly evaluated and therapy adjusted accordingly. Try to observe the patient in the immediate post-op days, and listen to the nurses and patients either using pain scales or direct inquiry. Analgesic drugs should be given regularly in a stepwise approach, and pain therapy must not be based on patient's demand (Table 16.7).

Deep Vein Thrombosis (DVT) Prophylaxis

DVT is best prevented by adequate hydration, compression stockings, and early mobilization. DVT and bleeding risk factors should inform the need for pharmacological DVT prophylaxis with enoxaparin 40 mg SC, once a day. Halve the dose in the face of liver-kidney injury and/or body weight less than 45 kg. Depending on the surgery, ability to mobilize, and discharge date from surgery, enoxaparin can continue for 7–14 days. If possible, check platelets before starting and twice a week from the fourth day. Beware of heparin-induced thrombocytopenia.

Table 16.7 Dosages for common analgesics

	Infant (0–12 months)	Child	Adult	Note
Paracetamol	10 mg/kg TID or 7.5 mg/kg QID; PO or IV	15 mg/kg QID; PO or IV	0.5–1 g QID; PO or IV	
	Max: 30 mg/kg/day	Max: 60 mg/kg/day	Max: 4 g/day	
Ibuprofen	Do not give under 6 months	10 mg/kg (up to 200 mg) QID; PO or IV	400 QID or 600 mg TID; PO or IV	Use 3–8 days!
		Max: 40 mg/kg/day (up to 800 mg)	Max: 3.2 g/day	Beware of asthma and renal impairment
Diclofenac	Do not give under 6 months	0.5–1 mg/kg BID-TID; PO	75 mg BID; IM or IV	Use 3–8 days!
		Max: 3 mg/kg	50 mg TID; PO	Beware of asthma and renal impairment
			Max: 150 mg/day	
Tramadol	Not recommended	0.5–2 mg/kg QID; IV, IM, SC, or PO	50–100 mg QID or Q4h; IV, IM, SC, or PO	
		Max: 8 mg/kg/day	Max: 600 mg/day	
Morphine	0.05–0.1 mg/kg QID or Q4h; IV, IM, SC, or PO	0.05–0.1 mg/kg QID or Q4h; IV, IM, SC, or PO	5–15 QID or Q4h; IV, IM, SC, or PO	Respiratory depression,
	Give IV in increments	Give IV in increments	Give IV in 2 mg increments	Titrate to effect
Pethidine	Not recommended	1 mg/kg QID or Q4h; IV or IM	50–100 mg QID or Q4h; SC or IM	Titrate to effect
		Give IV in 0.25 mg/kg, increments	1 mg/kg QID, IV,	
			Give IV in 10 mg increments	
Pentazocine	Do not give under 1 year	0.5–1 mg/kg TID-QID; IM-IV	30–60 mg TID or QID; IM-IV	
Fentanyl	0.5–2 µg/kg; IV or IM	0.5–2 µg/kg; IV or IM	50–100 µg; IV or IM	
Nalorphine		1 mg IV	3–10 mg IV	Opioid antagonist,
				Repeated until clinical improvement observed
Naloxone	10 µg/kg IV initially then followed	5–10 mcg/kg IV	50 µg/kg IV increments	Opioid antagonist,
	10 µg/kg/every 90 min, IM		Up to 2 mg	Repeated until clinical improvement observed
Carbamazepine			100 mg BID; PO	Use for neuropathic pain
			Max: 1200 mg/day	Titrate to effect
Gabapentin		30 mg/kg/day;	300 mg TID; PO max: 3600 mg/day	Use for neuropathic pain
		Start 10 mg/kg OD; PO		Titrate to effect
		Increase to BID, then to TID		
		(Not recommended except for amputation)		

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Part III

Adult Trauma

17 Introduction to Trauma in Austere Environments

Michelle Foltz, Nadine B. Semer, Richard A. Gosselin, and Geoffrey Walker

Introduction

Until recently, injuries were considered accidental events, occurring randomly—unpredictable and unavoidable. The 1996 Global Burden of Disease (GBD) study showed that at the population level, injuries and their sequelae are like all other diseases and conditions that lead to premature death or ill health. Many people were surprised to learn that traumatic injuries accounted for 15% of the total global burden of disease. No surgeon with experience in low- and middle-income countries (LMICs) would be surprised, as injuries in general—and road traffic injuries (RTI) in particular—are widely acknowledged as the "neglected epidemic" of the developing world.

Vulnerable road users—children, pedestrians, and cyclists—are common victims. Besides the absolute increase in road traffic crashes in LMICs, there are more deaths and injuries per crash than in high-income countries (HICs), as each vehicle carries many more passengers. In the USA, drivers account for more than 60% of vehicular deaths; in LMICs they account for less than 10% (GBD). Considering the poor quality of road infrastructure, the number of unroadworthy vehicles, the lack of road safety laws or their enforcement, the paucity of prevention strategies, the poor quality of prehospital care, and often the hospital care itself, it comes as no surprise that the burden of vehicular injuries is increasing exponentially.

The lack of any social net is another significant difference between HICs and LMICs directly affecting orthopedic trauma care. There are few mechanisms by which an injured worker, even when injured on the job, is compensated for the injury, missed time, or wages. Because of these social hardships and other true or hidden costs, patients are reluctant to seek treatment unless absolutely necessary and often object to surgical treatments that involve prolonged hospitalization and extensive rehabilitation. For patients coming from remote areas, even if treatment is free, time away from fields and transportation costs are barriers to care, and certainly barriers to follow-up. Many patients do not return for follow-up unless there is a problem. All these elements need to be factored in when considering treatments, and whenever possible, serious consideration should be given to a "one-shot" treatment approach.

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Acute Care

Due to distances between facilities, poor roads, and lack of emergency transport, a volunteer surgeon should not expect the sort of emergency room trauma resuscitation common in Western hospitals. When treating the injured in an emergency setting in a foreign country, it is beneficial to have a local doctor, nurse, or even an orderly interpret language and culture. They can help deal with the family in light of social expectations and in accordance with hospital requirements.

All acute trauma cases require evaluation using the Advanced Trauma Life Support protocols. Even if a patient presents late and has received treatment elsewhere, a brief but thorough primary survey, evaluating ABCDEs, should be done followed by a secondary survey with a neurologic exam. The mnemonic AMPLE (Box 17.1) can be used to obtain a useful history.

Box 17.1 Mnemonic AMPLE

AMPLE
A-allergies
M-medications
P-past illnesses/pregnancy
L-last meal
E-events leading to injury time and date

Dehydration is common and often unrecognized. Even if the patient arrives with an intravenous line in place and fluids hanging, check the type of fluid and that the lines are open (Fig. 17.1). A Foley catheter for serial determination of urine output and color, as well as heart rate, respiratory rate, and blood pressure, may be the only clinical parameter for ongoing assessment. If the emergency department has a pulse oximeter, use it or share it with another patient. An initial Glasgow Coma Scale assessment should be recorded, even without indication of head injury (see Appendix 1).

Remove previously applied bandages and splints; sutures should be removed if there is any doubt concerning the cleanliness, tension, suitability of the repair, or the extent of the underlying injury, especially with the possibility of an open fracture or infection. Complete disrobing may be difficult due to crowding, lack of curtains or private exam rooms, and culture. In certain societies, examining female patients, even by a female doctor, can lead to misunderstandings. A female staff member should be present; ask what is appropriate; explain what you plan to do and why. Families and patients used to offhand treatment in autocratic health systems usually respond positively when treated with respect and given thoughtful explanations [1].

Pay special attention to the feet during the physical exam. Rubber flip-flops are common footwear, and children often go barefoot, making crush and deep avulsion wounds common (Fig. 17.2). Foot wounds often have a distally based degloved, flap component. A minor but unaddressed foot injury can give more long-term disability than an open femur fracture.

X-rays, if the facilities are available, should be taken, but do not let the lack of advanced imaging or inadequate pictures interfere with clinical judgment. Patients with suspected femur fractures are often given one proximal femur x-ray and a distal femur x-ray in another plane (Fig. 17.3). A full complement of trauma films is unlikely, while the logistics of additional views after admission to a ward can be complicated. Digital films and processors are rare except in the private setting (Fig. 17.4). View boxes are few in number, and x-rays are often viewed and assessed while held up to a window or light (Fig. 17.5), leading to faulty readings and missed subtleties. A white lab coat taped to the window will improve the detail of an x-ray read through window light (Fig. 17.6).

Many middle-income countries are developing trauma systems, but few hospitals in low-income countries have the staff and facilities for good triage. Emergency departments (ED) can be chaotic (Fig. 17.7) with triage based on the demands of a powerful family or the perceived importance of the hospital staff hierarchy. It may not make medical sense.

Fig. 17.1 (**a**) This patient arrived in the OPD with an IV line in place and bottle strapped to a wooden pole wrapped in cloth for easier grip. Note bamboo splint over a swath of material protecting her left closed femur fracture. Local clinics and first aid posts often have slatted bamboo splints readymade for immediate use. (**b**) Child arriving in hospital from clinic on *moto* taxi with IV line in place

Fig. 17.2 (**a**) Avulsion of dorsum of foot—traction injury from a car's tire running over child's foot after she was knocked down. (**b**) Appearance after cleaning. (**c**) Appearance after sharp debridement. In children these wounds often develop enough granulation to accept an STSG. Soft tissues that have lost bone can be used as a fillet flap

Fig. 17.3 A surgeon holding an x-ray up to light from a window because there is no view box in the operating theater. Note x-ray is inadequate to assess the extent of injury of the hip, proximal femur, or knee

Fig. 17.4 X-rays drying outside

Fig. 17.5 Pelvic x-ray of child with AVN of R hip due to sickle cell disease read through window light

Fig. 17.6 The detail of the x-ray shown in Fig. 17.5 is improved when a white lab coat is interposed between the window and x-ray

Hospitals may not have staff for night cases, or obstetrics may take precedence, leaving trauma cases until the next morning, the next afternoon, or a couple days later. Hospitals that require payment up-front for services or overcrowded facilities in which the patient cannot obtain a bed can delay the initial surgical treatment. To avoid unnecessary frustration, try to find a modus operandi that will give the patient the best treatment within the systemic limitations. Remember, there is often more than one way to treat an injury that gives a good outcome.

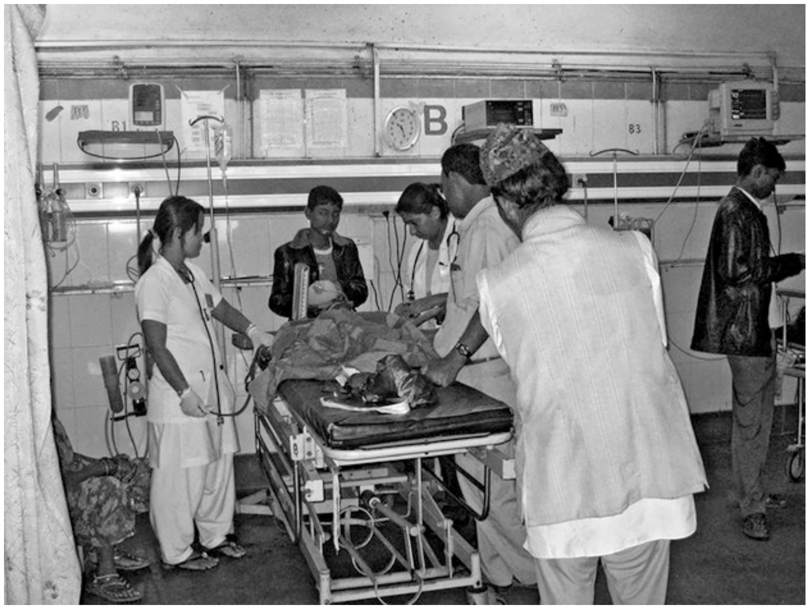

Fig. 17.7 A family member has been given the task to manually ventilate his relative while a nurse and doctor perform medical chores and other family members observe

If the injured patient is unable to go to the operating room in a timely manner, clean the wound in the emergency department under whatever sedation, systemic analgesia, or local anesthetic is available, using the cleanest fluid. Apply a bulky sterile or clean dressing. Splinting and elevation of all extremity injuries help relieve pain and prevent further local injury. Hospitals may have Steinmann pins and frames for traction, but do not be surprised if handed a mallet with which to hammer in the pin. Due to lack of equipment and supplies, improvisation is common.

Degloving Injuries

Degloving injuries—whereby large swathes of skin are lifted, avulsed, or abraded from the underlying muscle—often include a significant crush as well as a shearing element. The tissue damage is often more extensive than it initially appears (Fig. 17.8).

Degloving injuries with flaps need to be closely evaluated. Explore and clean under all exposed undermined tissue, removing nonviable components. If the skin appears viable and the edges bleed, try to tack it loosely back in place but under no tension. Dress the extremity with loose, splinted dressings, and recheck in 1–2 days in the operating room to assess tissue demarcation. Even with optimal treatment, patients with degloving wounds are difficult to treat. The dead space under the flap and dying, damaged tissue make a great culture media, and patients can become ill very quickly (Fig. 17.9).

Open Fractures

In countries where the motorbike and bicycle are the usual form of transport, open fractures are common, with open tibial fractures the most common. Patients often present after 2–3 days without treatment or with inadequate treatment, making good outcomes difficult or impossible (Fig. 17.10).

Prophylactic IV antibiotics appropriate to the injury, local availability, or hospital protocols are a mainstay in open fracture treatment and need to be given as early as possible. First- or second-generation cephalosporins are the frontline antibiotics with an aminoglycoside added for higher-grade open fractures and penicillin, Flagyl, or clindamycin added to cover specific contamination [2]. The incidence of antibiotic resistance in developing countries is

Fig. 17.8 On initial debridement, the extent of damage of this distally based flap was unrecognized. The tissue under the flap was not explored, and the flap was reapproximated under tension

Fig. 17.9 Circumferential degloving injury of left leg, with loss of skin from mid-thigh to midfoot after the leg was run over by a heavy vehicle at work. The patient was hypertensive and diabetic, and the leg was not salvageable

a considerable problem due to uncontrolled prescribing practices by untrained personnel, ready availability without prescription, and irrational patient demand [3]. Though nonmedical use of antibiotics in agriculture appears less prevalent, in some countries second- or third-generation cephalosporins are frontline antibiotics that patients with noninfectious problems expect to receive. Pay attention to tetanus immunization and cover aggressively, as patients often do not remember if or when they were vaccinated.

The Gustilo classification of open fractures focuses on the extent of soft tissue injury and is widely used globally. Classification is most accurate when done at the end of debridement in the

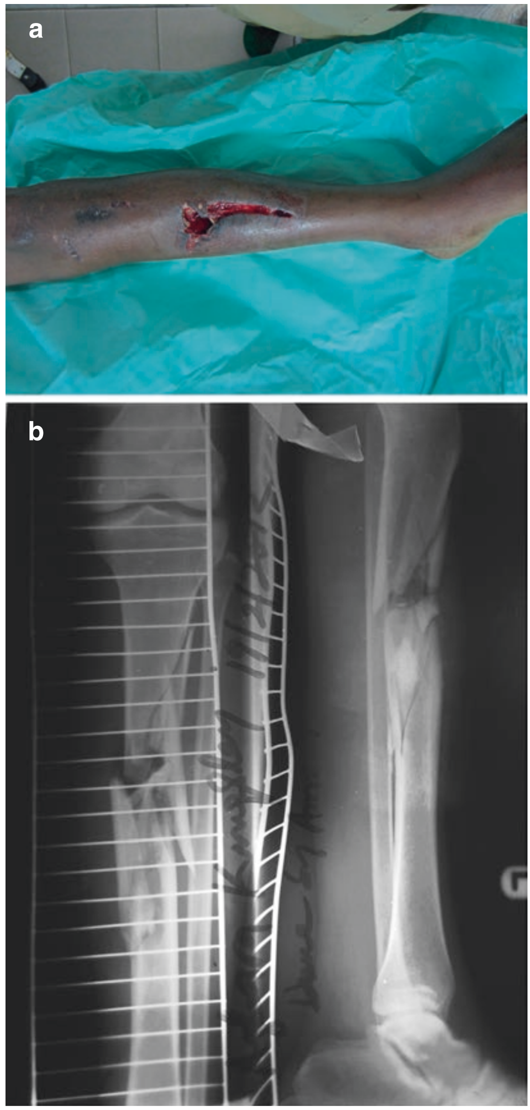

Fig. 17.10 (**a**) This patient was a passenger on a motorcycle taxi. He spent 2 days in another hospital without treatment. At the time of his presentation, the wound had a foul odor and the soleus muscle was necrotic. (**b**) The major bone fragments seen in his x-ray had no soft tissue attachments

operating room (OR), though an assessment in the ED helps set the parameters for the initial treatment (Box 17.2).

As in other open injuries, clean and splint the open fracture in the ED following local protocols. The controversy in the West concerning the appropriate time frame open fractures should be

Box 17.2 Gustilo and Anderson Classification of Open Fractures

Type I

Clean wound smaller than 1 cm in size. Assumes a simple fracture pattern.

Type II

Soft tissue injury >1 cm but <10 cm without extensive soft tissue damage. Assumes minimal degloving and periosteal stripping and not more than moderate contamination or comminution.

Type III

High-energy injuries, with substantial soft tissue injury, periosteal stripping, and/or some degree of crush. Segmental fractures, bone loss, farmyard injuries, and high-velocity GSW.

Type IIIA

Large soft tissue injury or flap, though usually less than 10 cm. Adequate soft tissue remains to cover the bone.

Type IIIB

Extensive soft tissue injury, bone loss, devascularization, and/or massive contamination. Inadequate soft tissue to cover bone without a flap.

Type IIIC

Fractures with major arterial injury requiring repair.

taken to the OR exists in developing countries, with the addition of rules and protocols that can prolong the time to debridement.

In the OR, apply an inflatable tourniquet, if available, even if you do not think you will use it. Prepping and draping procedures are often a matter of faith and precedent with nursing staff, who may resist well-meaning suggestions. If the prep appears substandard, ask to prep again, even a third time, until the wound and extremity are as clean as the situation allows. Due to lack of draping material, the initial washout may take place using a non-sterile rubber drape and a plastic apron.

After removal of gross contamination, copious irrigation, and wound excision, re-prep and drape the patient. Enlarge and expose the deeper tissues underlying the wound. Remove all muscle that is discolored, of mushy consistency, fails to contract when irritated, and does not bleed when cut.

If the skin injury does not appear to be full thickness, it is sometimes safe to leave moderately damaged skin for further consideration at an early second OR visit, as skin can be quite resilient. Fascia that is grossly contaminated, infected, ragged, or discolored should be removed. Pieces of bone unattached to soft tissue should be removed. No matter how large or structurally important a piece of cortical bone is, if it is devitalized and has no blood supply, it should be removed. Retain as much periosteum as possible. The goal of debridement is to reestablish a healthy, vascularized soft tissue bed so the injured bone or the bone defect can be covered.

The surgical incisions made to enlarge the wound can be closed without tension at the end of the debridement, but the original wound should be left open and covered with a sterile dressing. Even if it appears that the injury wound can be closed, do not close it. Flaps of skin sutured under tension in an attempt to cover bone will fail, leading to further soft tissue loss, increased risk of infection, and extended hospitalization (Fig. 17.11). Initial debridements of high-grade open fractures are

Fig. 17.11 Appearance of a leg 4 days after the initial debridement of a Grade IIIB open tibia fracture from RTI. It is unlikely that the entire anterolateral distally based flap would have survived, but the solitary stitch placed under tension to cover the bone has made the situation worse

rarely totally satisfactory, especially if done by a surgeon who is inexperienced with trauma in that particular setting.

Antibiotic impregnated beads as an adjunct to wound treatment are valuable in open fracture care. If polymethyl methacrylate cement is available, even outdated, any thermostable and water-soluble antibiotic in doses of between 2 and 4 g can be added to cement powder to make beads or spacers. Inexpensive liquid gentamicin is usually available, as opposed to expensive tobramycin. Six 80-mg vials of gentamicin added to the cement at the time of mixing will give satisfactory antibiotic levels [4].

Dress the wound with dry gauze, fluffed for absorbency, secured with an elastic bandage in a figure of 8 configuration to prevent circular constriction.

An external fixator is a useful tool after debridement to treat the soft tissues of an open tibial fracture. Pin placement should remain outside the zone of injury and take into consideration anticipated flaps or skin grafts. Fixator pins are often of poor quality or, if reused, out of true. Unless the local surgeon following the case is comfortable with the long-term treatment of fractures in external fixators and familiar with the system at hand, it is best to remove external fixators when they are no longer needed to treat the soft tissue injury and convert the immobilization to either short-term or definitive treatment in plaster of Paris or traction. Pin track infections and equinus deformity are common problems (Fig. 17.12). The first is avoided by predrilling or placement of pins by hand and the second by external ankle splinting, exercises, elastic bands, and monitoring.

Fig. 17.12 (**a**) The maximum right ankle dorsiflexion after 6 weeks in an external fixator. Equinus contracture is preventable by paying attention to splinting and directed exercises. (**b**) One of any number of makeshift solutions to preventing equinus deformity

Open femur fractures, with a thicker and more vascular soft tissue envelop than tibial or forearm fractures, may allow earlier and more consistently successful delayed primary closure and definitive treatment by traction or internal fixation and can initially be treated with high tibial, distal tibial, or calcaneal traction as opposed to external fixation.

Open humerus and forearm fractures, if unstable or with significant soft tissue loss, may benefit from short-term external fixation. Elbow stiffness and nerve impalement are potential problems. Splinting a severely injured forearm in neutral rotation leaves the extremity in the most functional position.

Plaster of Paris (POP) has many uses in the emergency setting after debridement. A robust back slab, U-slab, or three-sided gutter splint may offer better and quicker initial immobilization than an external fixator conjured from a jumbled set of leftover clamps and bars with a surgical team that is unfamiliar with orthopedic cases.

Grade one open fracture wounds will heal by secondary intention and do not necessarily need to return to the operating room for closure after initial debridement. Grade 2 and 3 wounds should return to the operating room in 2–5 days for skin closure, skin graft, flap, or re-debridement. Repeat visits to the OR should continue as needed until the bone and soft tissues provide a clean, stable vascular bed that can be covered with healthy tissue.

Inviting a colleague to look at a wound during debridement is a good policy, especially if the wound will require extensive reconstruction or there is any question of limb or tissue viability. Though it is expensive and time-consuming for the patient to return to the operating room, resist the temptation to do early dressing changes on the ward or to close wounds under tension, since these will increase the possibility of infection and may lead to more expensive and complex surgery in the future.

A short-term volunteer is unlikely to be present throughout the entire lengthy treatment of most open long bone fractures. Written communication over and above that given in the Gustilo classification—such as wound size and depth in cms, projected ability to close the wound and how, degree of periosteal stripping, presence of degloving or vascular injury, extent of muscle damage, type of initial contamination, detailed history of procedures done, and a proposed plan—provides useful information for continuity of care. Write details about the injury on the cast or dressing with a Sharpie. Digital photos left on a hospital computer or a flash drive and sketches in the chart will add to the written description.

The determination of fracture healing—even with the latest imaging techniques and extensive trauma experience—is not always straight forward. In an austere environment in which imaging is limited to inadequate x-rays, healing may be more fraught with uncertainty. When a visiting surgeon is present only for a few weeks, there may be pressure from the family, patient, and hospital staff to make decisions on healing using minimal or inadequate criteria. These are cases that at home have the option of waiting, another imaging study, or consultation with a colleague down the hall. The choice to tackle the presumed non- or delayed union or to wait can be difficult, especially if the surgeon is not going to be present to take care of any potential complications. One nontechnical solution to determine healing used by SIGN surgeons is a "squat and smile" picture. The ready smile when asked to stress the fracture with an independent squat is a fair indication that the patient's fracture is healed (Fig. 17.13).

Hardware and Its Removal

The volunteer surgeon will be asked when plates, screws, or nails will be removed. Explain that the fixation needs to remain in place until the bone is healed clinically and radiographically, usually 12–18 months. At the same time, inform the patient and the family that hardware removal is usually not necessary. However, there are instances when it is (Fig. 17.14). If a patient requests removal on the advice of another practitioner, the history, exam, and x-ray should clarify if this is a ploy on the part of the practitioner for

Fig. 17.13 Three months after fixation of a highly comminuted sub-intertrochanteric femur fracture, the patient readily smiles when stressing the healing fracture with a full independent squat. (Courtesy of Dr. Sam Kiwesa)

Fig. 17.14 (**a**) Compromised skin of right lateral buttock tented over a proximally protruding K-nail. (**b**) X-ray of long K-nail

financial gain. Unfortunately, in some areas this is a common practice.

Without fluoroscopy, metal removal can be difficult. Screws break or their heads become overgrown with bone, and retrieving the buried end of an IM nail can be a frustrating procedure, with the potential for damaging the surrounding tissues. Make sure the x-rays on which one is basing the metal removal are recent, since hardware can be removed piecemeal, and patients are not always aware of what is present.

Fig. 17.15 This patient's radius fracture is healed, and his wounds are amazingly clean despite the exposed plate. However he has no money to pay for the metal removal

In situations where patients must pay and will not be admitted until payment is made, they may have had the money for the implant and the OR expenses to insert it but not for its removal (Fig. 17.15).

K-wires used for percutaneous or open fixation, especially in pediatric fractures that will need the pins for only 3–6 weeks, should be left protruding far enough outside the skin so they can be bent back on themselves for easy removal in the OPD. A pin cutoff at skin level will cause irritation and infection and be difficult to remove. Removing a buried pin will usually require a general anesthetic. Adults may tolerate a small incision under local anesthesia for buried pin removal, but there may be no sterile pliers or pin removal set in the OPD. Using "simple" K-wires without evaluating how they will be removed is another instance in which the short-term volunteer must be aware of what he or she is leaving behind.

Compartment Syndrome

Surgeons should be aware of the possibility of compartment syndrome when dealing with *all* low- and high-energy traumas, open or closed fractures, and especially injuries with a crush component. Tibial fractures are commonly associated with compartment syndrome followed by forearm and elbow injuries. In the developing world, compression from traditional treatments involving tight bandages and splints or irritating topical remedies and snakebite injuries are not uncommon causes.

The swelling due to compartment syndrome is clinically difficult to differentiate from that caused by the underlying injury, especially in the face of internal degloving. Deep pain that is more intense and out of proportion to normal expectations or pain that increases despite elevation and immobilization should alert the surgeon.

Pain on passive muscle stretch, with the fracture stabilized, is a reliable sign of increased compartment pressure especially in situations where cultural barriers make interpretation of pain levels difficult. Paresthesias may be a relatively early indicator but are hard to assess. Pallor and paralysis are late signs and limited in early diagnosis, while distal pulses can be present in the face of dead muscle.

At the first indication of possible compartment pressure elevation, all constricting bandages should be released while maintaining fracture stability. If bivalving or removing half of a plaster cast, splitting the cast padding along its entire length, and release of blood-soaked bandages or tight wrappings do not reverse the abnormal clinical signs, the patient needs emergency surgical decompression. Early administration of adequate intravenous fluids may prevent the concentration of metabolic by-products that can lead to renal failure of crush injuries, and supplemental oxygen will help maintain tissue oxygenation. Though the times given for ischemia to cause irreversible damage are 6 h for nerve and 8 h for muscle, do not wait, hoping for improvement. Pressure measurement gauges are unlikely to be present or, if present, unreliable.

Situations in which pain is difficult to evaluate—such as head injury, previous anesthesia, alcohol, or mind-altering drugs—can make the clinical diagnosis especially difficult. If in doubt, proceed with fasciotomy.

Surgical release of a compartment syndrome caused by a lower leg injury requires release of all four muscle compartments surrounding the tibia. This is most easily and thoroughly done using a 2-incision approach with a tourniquet in place but *not* inflated (video of two-incision release in leg: https://www.youtube.com/watch?v=ePXT1Lcfboc). A longitudinal medial incision placed about 2 cm posterior to the medial border of the tibia gives access to the superficial posterior and deep posterior compartments. An anterolateral longitudinal incision halfway between the tibial crest and the fibula allows the release of the anterior extensor and peroneal muscles. All individual fascial compartments need to be released, and any muscle that is discolored, of poor consistency, fails to contract when irritated, or does not bleed when cut should be considered nonviable and debrided (Fig. 17.16).

Upper extremity impending compartment syndrome is approached through a straight or curvilinear volar incision that releases the median nerve in the carpal canal and may be extended proximally above the elbow. The dorsal compartments are decompressed by a longitudinal straight dorsal incision, taking care to release the fascia over the wrist extensors in the mobile wad (video of forearm compartment decompression: https://vimeopro.com/orthotraumaassn/2015-surgical-technique-videos/video/187066285).

The skin and fascial wounds are left open and covered with non-constricting bulky dressings supplemented with an external fixator or robust plaster of Paris back slab or gutter splint to stabilize the fracture and prevent further soft tissue damage. The limb should be elevated just above the heart level to prevent swelling from venous congestion. Fasciotomy wounds should be treated like wounds after debridement of an open fracture and reevaluated in the operating room in 2–5 days for possible skin closure, re-debridement of muscle, or skin grafting. If only one of the two wounds in the leg can be closed, leave open the one with the best soft tissue bed for later skin grafting. Most often this is the anterior lateral wound. Rows of short relaxing incisions on both sides of the wound may allow skin closure without tension. Rubber bands laced through skin staples, loops of suture, or along K-wires threaded at the edges of the wound can be used to gradually close a wound over several days [5]. It is better to skin graft a fasciotomy than close it under tension.

If a compartment syndrome is present but no operating room is available, there is no anesthesiologist, and timely transfer is not an option, proceed with the fasciotomy under local anesthesia in the ED or at the bedside.

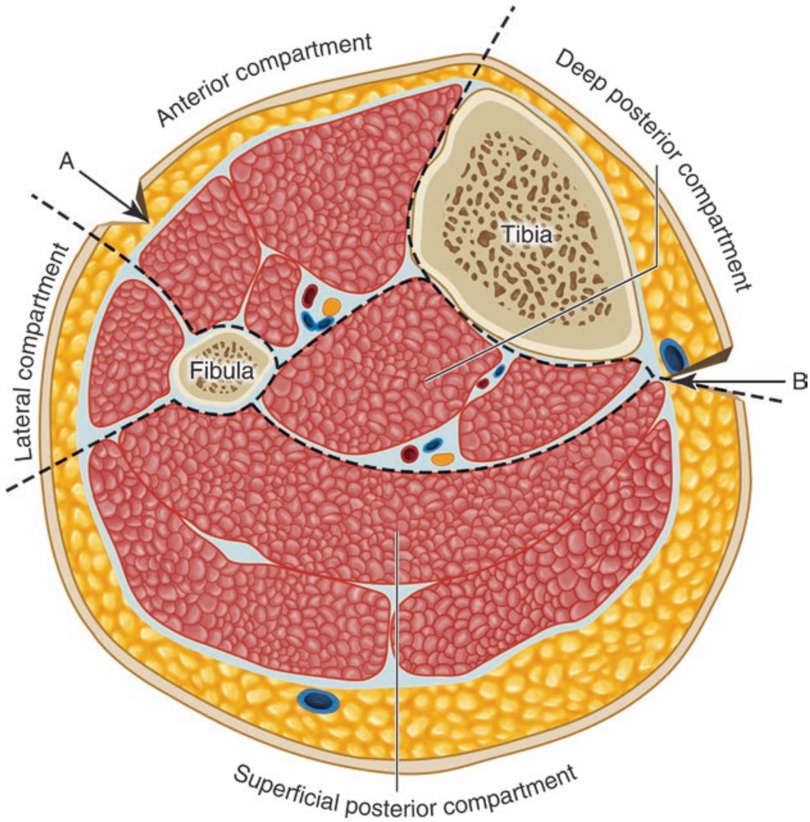

Fig. 17.16 Cross section of tibia showing the four compartments: anterior, lateral, superficial posterior, and deep posterior—that should be released at the time of fasciotomy. *Arrow A*—place incision halfway between anterior tibial crest and fibula to release the anterior and lateral compartments. *Arrow B*—place incision just behind the posterior-medial border of the tibia to allow access to both superficial posterior and deep posterior compartments

Fat Embolism and Deep Venous Thrombosis

Patients with multiple long bone fractures and/or severe thoracic injury are noted candidates for fat embolism syndrome, but this complication can occur with any trauma. Hypoxia, pulmonary distress, petechiae on the upper anterior chest and upper arms, and non-focal neurological deterioration are the classic signs. Primary supportive therapies to prevent respiratory compromise include fluids and oxygen while maintaining adequate urine output.

Safe methods to protect trauma patients from deep vein thrombosis (DVT), such as low molecular weight heparin or compression boots, are usually too expensive and unavailable in austere settings. The lab tests necessary for monitoring other forms of anticoagulation may be beyond the means and capabilities of the patients and the health system. Aspirin may be all that is available and should be used. Ask how the local surgeons handle this problem and take cues from them, realizing that the prevalence of DVT is unknown and little studied in most resource-limited situations, and the staff may not be attuned to this complication. The best preventive solution is early mobilization.

Burns

Due to heating and cooking with open fires or poorly constructed stoves, severe burns are common in developing countries. Other medical personnel are usually available to resuscitate these patients. But if not, the main treatments are tetanus prophylaxis, generous analgesia, fluid management with adequate hydration, and nutritional support (Box 17.3; Fig. 17.17).

A visiting orthopedic surgeon's most important role in burn management may be preventing contractures, especially in the hand. Gentle eleva-

Box 17.3 WHO Resuscitation Burn Protocol for Adults and Children

Fluid requirement in first 48 h

Hours since burn—fluid requirement

0–24 h—2 ml/kg X %TBSA* of ringers (1/2 in first 8 h and 1/2 in following 16 h)

24–48 h—guided by urine output with target 0.5 ml/kg/h.

Burns >50% TBSA use the 50% in calculation

Inhalational injury and electric burns use 3 ml/kg X %TBSA

*TBSA—total body surface area, counting second- and third-degree burns

tion of a burned extremity will decrease swelling and can prevent a relatively superficial burn from becoming full thickness. Circumferential burns, especially on extremities, may require escharotomy. Early excision and grafting of large burns can prevent severe contracture. Early functional splints and ROM exercises will reduce disability.

Patient Safety

In austere environments patient safety can appear to be of little concern: trolleys lack side rails, insufficiently recovered patients are left unsecured and unattended, orders ignored. The rea-

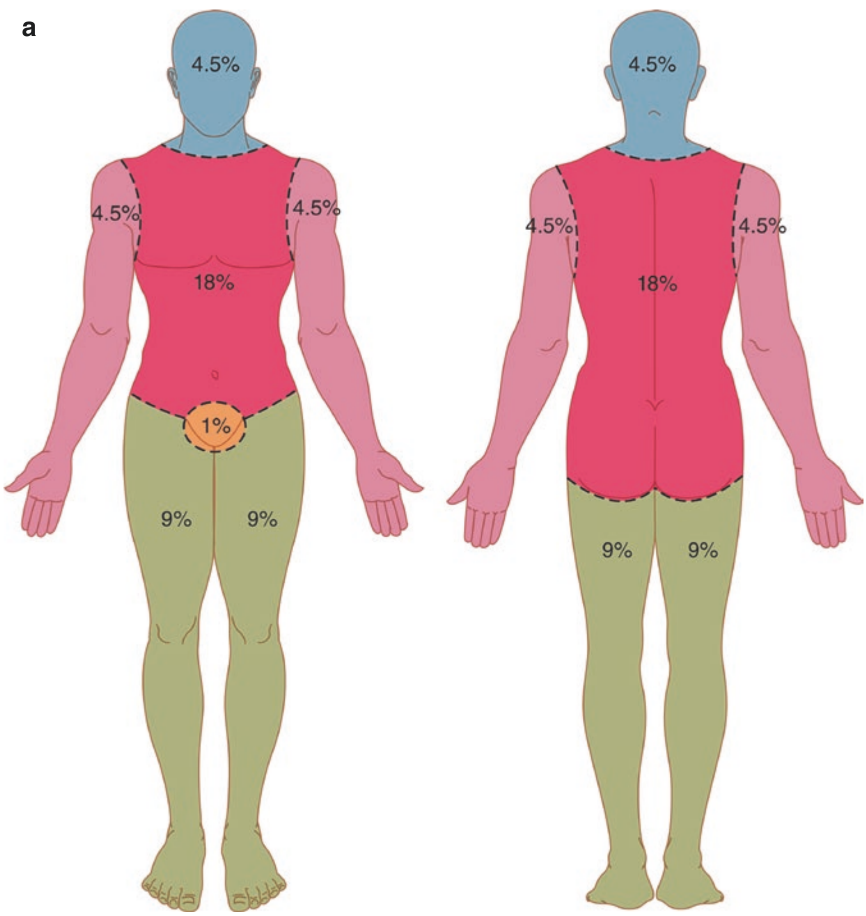

Fig. 17.17 Determine the extent of burned area of the body by "rule of 9 s," counting the surface area with second- and third-degree burns. The head, each entire arm, and the entire front or the entire back of each leg individually makes up 9% TBSA. The anterior trunk and posterior trunk make up 18% each

b

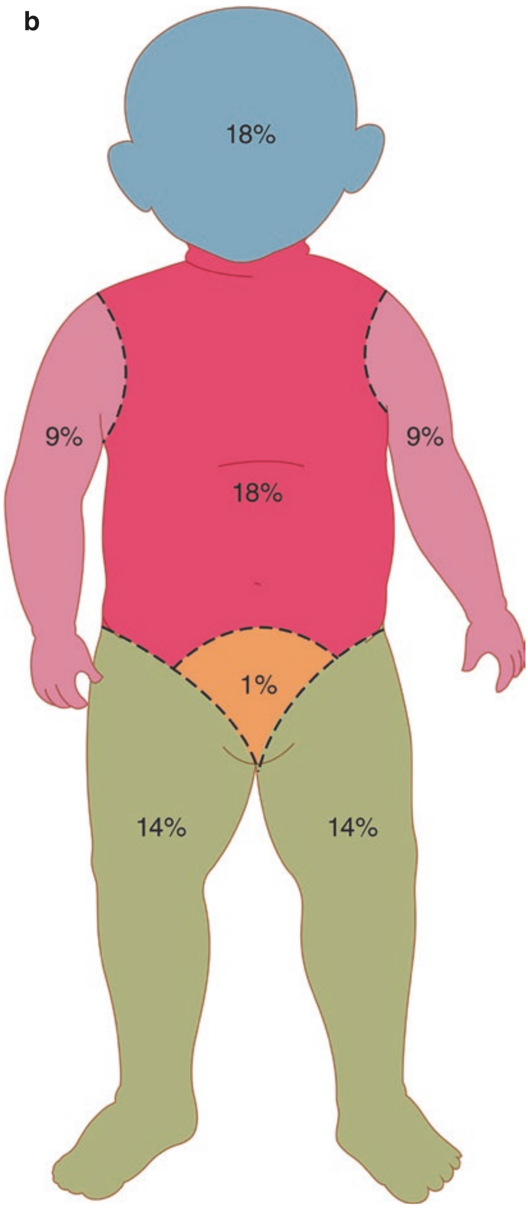

Fig. 17.17 (continued)

sons are numerous and reflect the lack of human and financial resources and difficulty identifying and managing risk. The implementation of surgical safety guidelines in Western surgical practice has increased awareness of potential, avoidable problems and has improved safety records. No matter the situation, a checklist can be tailored to improve any surgical situation.

The WHO Surgical Safety Checklist (Appendix 2) provides a basic outline of information and actions that when followed focuses attention at critical times in a procedure to alert the team to possible complications and untoward events. If no checklist is in use, a visiting surgeon can help to write one with the input of the surgical staff to suit the situation. Having the nurses responsible for initiating the "time out" before each surgery and documenting its completion can increase compliance and encourage teamwork (Fig. 17.18).

Strategies When There Is No…

When there is no fluoroscopy, do not hesitate to open closed fractures for fixation, assuming all other conditions for open treatment are met. When done cleanly with careful soft tissue handling, there should be no increase in infection rate. Even if fluoroscopy is present but is temperamental, it might be best to teach a technique where it is not required, so that your local colleague will be able to do a similar case in the future when the fluoroscopy does not work.

When CT scan is not available, try oblique views or axial views. Go to the x-ray room; help the technician position the patient. The combination of images from these less often used views when combined with one's knowledge of anatomy should allow the generation of an "internal CT scan" image.

Accept clinical judgment. Solving problems by using the clinical skills learned in medical school, but often lying dormant since, is one of the most rewarding aspects of working in developing countries.

Have the hospital make equipment. Most hospitals in developing countries have workshops that can sharpen osteotomes, make lead hands, fabricate triangles for IM tibial, and retrograde femoral nailing (Fig. 17.19), frames for elevating extremities, or drip stands (Fig. 17.20). Welders and carpenters in local bazaars are happy to help solve problems. Tailors are inexpensive and can follow simple patterns or sketched ideas. Many hospitals have their own tailoring unit. A couple hundred

Fig. 17.18 "Time out" has become an established practice at this hospital in Lebanon. Once the patient is draped and before the incision is made, everyone stops, and an unscrubbed nurse takes the staff through the WHO safety checklist, which is then recorded in the OT notes

Fig. 17.19 Two sizes of triangles of wood and covered with vinyl for doing SIGN retrograde femur and tibial nailing were made in the hospital's workshop. A stump elevator or "horse" is used during lower extremity amputation surgery. Before use they are covered with plastic garbage bags followed by a sterile cloth Mayo stand or x-ray cassette cover

dollars spent on local materials to make drapes and OR clothes will go a long way in improving the infection rate, even if they are not water impermeable (Fig. 17.21). Locally made items are less expensive, improve the local economy, and help establish self-reinforcing pathways for the local surgeons to solve their own problems. Or, when you see a need, make it yourself (Fig. 17.22).

When stuck with a particular problem that you cannot solve, take a picture and send it by smart-phone along with a description to a colleague, or the resident on call at your home hospital. Use the surgical videos on YouTube.

The goals in treating trauma—whether simple or complex, involving bone or not—boil down to restoration of function. Formal rehabilitation through physical or occupational therapy may be rudimentary, and a visiting orthopedic surgeon often needs to take on the added task of rehabilitation from the time of admission.

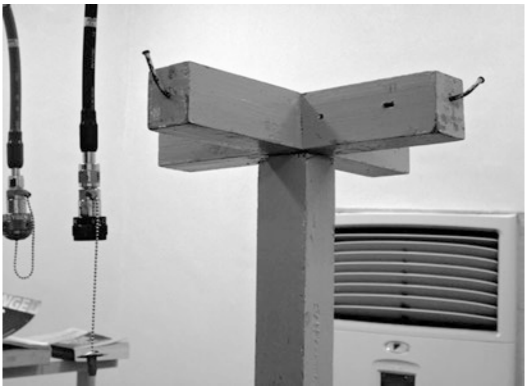

Fig. 17.20 Drip stand made in the hospital workshop of wood and nails

Rehabilitation does not require high-tech equipment—a simple rubber ball works for hand therapy. When that is not available, three or four tightly wadded up plastic bags can serve as a ball. A deep bowl of sand or uncooked rice makes a good medium in which patients can exercise their fingers. Much post-injury stiffness and deformity can be prevented by paying attention to the basic principles of splinting, elevation, and strategically timed and purposeful exercise and massage. Teach the patient exactly what he should do.

When language is a barrier, make sure someone who speaks a common language explains so that the patient can demonstrate what he is to do. Involve the families; they are critically important allies.

When stuck, ask for help. This does not have to be from another surgeon. The anesthesiologist and

Fig. 17.21 (**a**, **b**) Operating room gowns with back flap made by an Afghan provincial hospital's tailoring department. Though not waterproof, they provide adequate protection

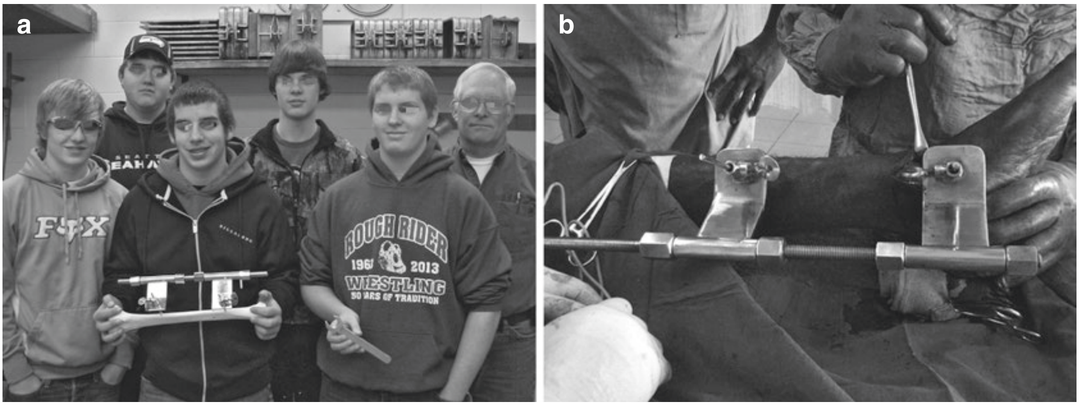

Fig. 17.22 Seeing a need and a challenge, two US orthopedic surgeons asked (**a**) the Port Angeles, Washington, high school machine shop students and their instructor to make an inexpensive fracture distractor. The <$100 distractor was made from scrap stainless steel. (**b**) The distractor in use for an ankle arthrodesis in Cameroon. (Courtesy of Dr. Sam Baker)

the nurses have spent many hours observing from the other side of the drapes, and they are aware of what is possible within the system. Follow "best practices" as you understand them, keeping to the basics and doing no harm. Remember, you are part of a medical team. Almost any skill or equipment deficiency can be covered by a cohesive team prepared to listen and work together.

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18 Trauma of the Shoulder and Humeral Shaft

Richard C. Fisher and Sonam Dorji

Introduction

The shoulder and humerus are common sites of injury from simple falls to high-energy road traffic crashes. The primary goal is to restore a stable and comfortable range of motion to permit lifting, pushing, pulling, and most importantly positioning the hand. With serious injuries and limited resources, it is not necessary to achieve "perfection" to reach the above goals. Often simple, predictable solutions are preferable to riskier and costly alternatives.

Since radiology services are variable in developing countries, emphasis is placed on the history and physical examination, so that treatment can be initiated while awaiting a definitive X-ray. If surgery plans involve fluoroscopy, it is best to have a backup plan before beginning the case. Where CT and MRI are available, they can be helpful in appropriate circumstances.

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Clavicle and Scapula Injuries

The scapuloclavicular complex provides the base support for the shoulder joint and the attachments for the controlling muscles. This complex is mobile on the trunk, supported only by muscle and a single bony attachment at the sternoclavicular joint, making injuries to this area common.

The Sternoclavicular Joint

Dislocations of the sternoclavicular joint occur from a medially directed force on the lateral shoulder or, rarely, a direct anterior blow. Anterior dislocations present with swelling and tenderness around a palpable bump over the medial clavicle. The dislocation is unstable, and patients do well with symptomatic treatment only.

Posterior sternoclavicular dislocations can potentially impinge on the brachiocephalic vessels, brachial plexus, esophagus, and trachea. Patients may present with a palpable indentation about the medial clavicle, although swelling may obscure this. Swelling, venous congestion of the arm, and difficulty breathing or swallowing signal a significant injury. Reduction is usually necessary and should be performed in the operating room with resources to perform an open reduction and life-saving vascular repair if the vessels are torn and bleed when the pressure is removed. If closed reduction is not possible, an open reduction

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with resection of a centimeter or less of the medial clavicle and ligament repair is indicated [1].

Clavicle Injuries

In its position as strut between the arm and thorax, the clavicle is frequently injured from a lateral or direct anterior force. The mid-shaft is the most common site (80%) followed by the lateral one-third [1]. Medial fractures are rare and often secondary to a space-occupying lesion in the bone. Most fractures can be treated closed with a sling or sling and figure eight dressing. While the healing time might be prolonged, nonunion is unusual and can be treated with internal fixation [2]. Determining fracture healing in the face of continuing clavicular pain and disability without CT can be helped using an apical lordotic chest X-ray (http://www.wikiradiography.net/page/Lordotic+Chest+Technique).

Open fractures, neurovascular injury, or displacement that compromises the overlying skin may require surgery. High-energy injuries causing a flail chest or an accompanying fracture in the shoulder suspensory ring might best be treated by stabilizing the clavicle fracture with a 3.5 mm dynamic compression plate and screws or a threaded intramedullary device. Smooth pins can migrate and should not be used in this region.

The treatment of lateral third fractures depends upon the relation of the fracture to the coracoclavicular ligaments. Most have minimal displacement and will heal using a sling. If the fracture disrupts or is medial to the ligaments, the displacement may preclude healing and require stabilization with a plate or ligament reconstruction. (The AO foundation surgery portal clavicle section has divisions on diagnosis, indication and type of treatment, approach, surgery, and after care. https://www2.aofoundation.org/wps/portal/surgery?)

The Acromioclavicular Joint

Intrinsically unstable, the acromioclavicular joint is held in place by soft tissue structures that are easily injured by a force applied to the tip of the acromion. The acromioclavicular (AC) ligaments resist anterior and posterior motion and are not as strong as the coracoclavicular (CC) ligament complex that resists upward displacement of the clavicle. A third restraint, the conjoined fascia of the deltoid and trapezius muscles, limits the displacement of the clavicle when the more inferior ligaments are torn.

Type I, II, and III injuries follow disruption of the AC and/or CC ligaments with displacement ranging from a few millimeters to several centimeters proximal displacement of the distal clavicle. These can be treated with a sling and range of motion exercise. The vast majority of Type III injuries will heal with a fully functional and pain-free shoulder but with a visible bump. Surgery in acute cases is best reserved for those whose skin is at risk from underlying pressure. Surgery for chronic cases is never indicated for cosmesis but only if residual pain is disabling and should consist of excision rather than attempt at repair.

In Type IV injuries, the clavicle is dislocated posteriorly through the trapezius muscle, and in Type V, the displacement is superior through the disrupted deltoid–trapezius fascia. Type VI injuries occur when the tip of clavicle becomes trapped inferior to the coracoid process and behind the conjoined tendon (short head of biceps and coracobrachialis). The latter three injury patterns usually need surgical treatment to place the distal clavicle in a functional position.

Scapula Fractures

Fractures of the scapula are usually the result of high-energy blunt trauma either from a direct blow or an axial load. Seventy-five percent are secondary to road traffic crashes [1]. While infrequent, they are important because of the potential for associated injuries to the brachial plexus and chest. Recognition of either severe chest trauma or a scapula fracture should prompt a careful examination for the other.

Scapular fractures are classified by region: body, spine, glenoid neck, glenoid fossa, acromion, and coracoid process. In general isolated fractures in these locations with minimal displacement can be treated successfully with a sling, gradually progressing to ROM exercises, and finally muscle strengthening as healing occurs.

The most significant injury pattern involves the superior shoulder suspensory complex (Fig. 18.1) that provides the support base for shoulder joint function. It includes the glenoid, coracoid, CC ligaments, AC joint, and acromion, with the major bony support from the clavicle and scapular neck. Injury of two or more structures in the ring can potentially cause instability. The concept of the "floating shoulder" involves fractures of the scapular neck, the mid-clavicle, and the humerus.

Treatment of this injury is controversial, but fractures with minimal displacement, <5 mm in the scapula and up to 10 mm in the clavicle, will reportedly do well with nonoperative care [3, 4]. Fractures with greater displacement should be considered for surgical stabilization. Clavicle fixation with a plate and screws is often sufficient to reduce the glenoid displacement and stabilize the ring. It has been suggested that both fractures in the ring need internal fixation, but each case must be evaluated individually [4].

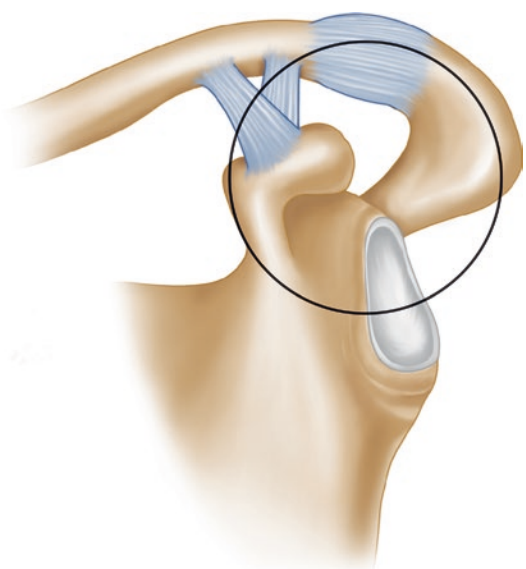

Fig. 18.1 Anatomy of the superior shoulder suspensory ring

The most severe form is the scapulothoracic dissociation, in which the entire scapula–humerus–clavicle complex is "avulsed" from the chest wall, either through disruption of the bone or soft tissues. This requires high energy, and the clinical diagnosis is not always easy but is important to recognize, as there is a high incidence of associated neurovascular injuries. Close monitoring for vascular complications is necessary. Unless arterial repair is needed, the treatment is conservative.

Rotator Cuff Tendon Injuries

The rotator cuff tendon, made up of the conjoined tendons of the supraspinatus, infraspinatus, and teres major muscles, engulfs the humeral head and is responsible for the smooth abduction of the glenohumeral joint. Disruption of the tendon may occur from acute trauma in younger people or from a degenerative tear in people over 60 years of age. Acute tears associated with major trauma to the shoulder area may need surgical repair. Chronic degenerative tears are preceded by pain with shoulder abduction and tenderness beneath the acromion. Begin treatment with rest, range of motion exercise, muscle strengthening, and anti-inflammatory medication.

Glenohumeral Dislocations

Anterior Dislocations

Anterior dislocations outnumber posterior dislocations by about 8:1, and the two can be distinguished by both history and physical exam. The initial anterior dislocation usually follows trauma with forced abduction and external rotation of the arm [5]. The patient maintains his arm in slight abduction and external rotation; internal rotation is blocked, and there is a "squared-off" appearance to the shoulder. Anterior shoulder dislocations may have associated axillary nerve or brachial plexus injuries, making an initial neurovascular exam necessary.

Appropriate X-ray views including a scapular AP, trans-scapular lateral (or Y), and axillary lateral (Fig. 18.2) should be done to confirm the diagnosis and rule out associated fractures before closed reduction. The humeral head is seen anterior to the "Mercedes Benz sign" in the trans-scapular view (video of basic X-ray anatomy of the shoulder: http://www.youtube.com/watch?v=h-cA9hYp0Ok) (http://www.youtube.com/watch?v=GtwONEsPLjc).

Posterior Dislocations

Posterior dislocations result from trauma in about two-thirds of cases, but the remainder occurs during seizures or electrical injuries. Since the dislocation is directly posterior, the shoulder deformity is not as obvious as with anterior dislocation and is often missed. The classic findings are shoulder

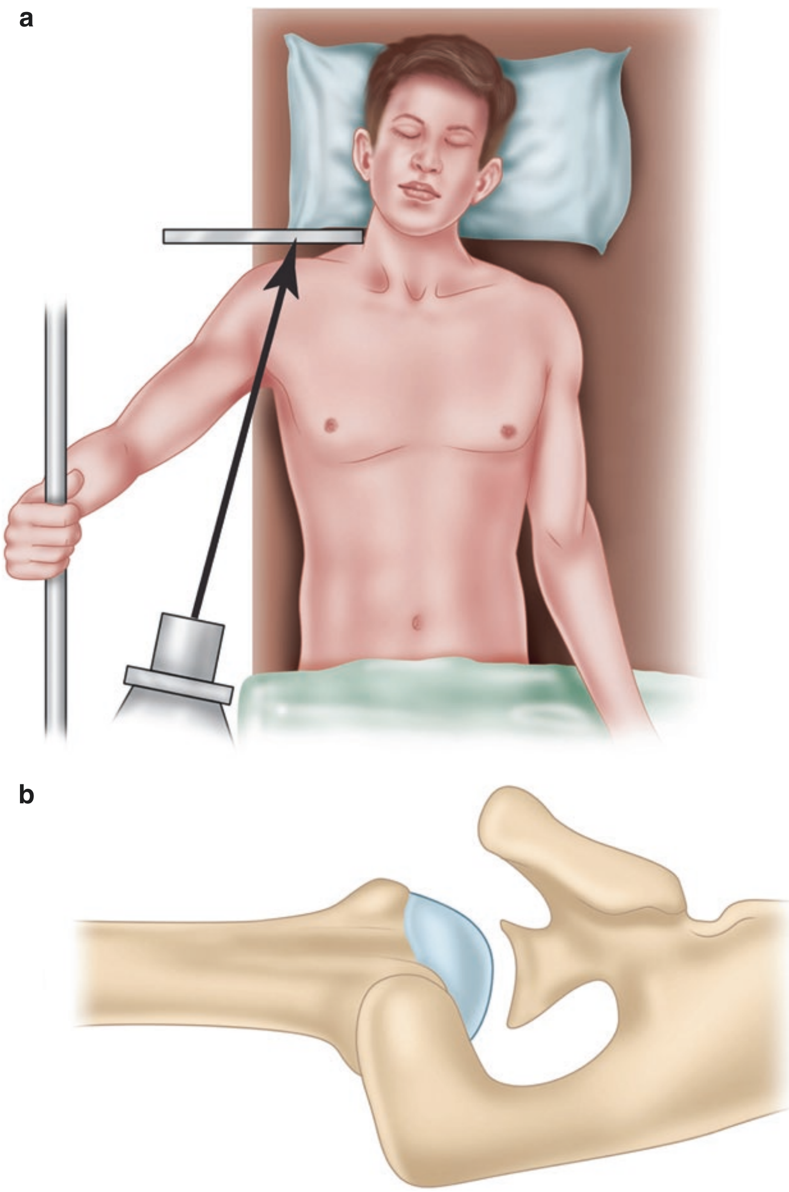

Fig. 18.2 (**a**) Illustration of how to take axillary lateral view of shoulder with minimal shoulder abduction. The patient's head and neck are bent away from the X-ray plate, the elbow is flexed, and the injured extremity is stabilized by holding an IV stand. (**b**) X-ray shows coracoid process, the acromium overlying the humeral head and true lateral views of both humeral head and glenoid

pain with loss of external rotation and fullness over the coracoid. X-rays often appear normal in the anterior–posterior view, making axillary or scapular lateral views necessary. Closed reduction for acute posterior dislocations is usually successful. The "lightbulb" sign seen on the anterior–posterior view of a posterior dislocation may be helpful (https://www.imageinterpretation.co.uk/shoulder.php#Post_dislocation).

Closed reduction within <3 weeks for both anterior and posterior dislocations is usually successful. If closed reduction is not possible, the two remaining options are open reduction and early rehabilitation allowing the shoulder to remain dislocated. While many surgical approaches have been described [6, 7], all report difficulty re-placing the humeral head into the glenoid and having it stay. Some have used pins through the head into the glenoid to secure the reduction. Most report limited range of motion post-op, while injury to the axillary nerve is common. Results are worse the longer the shoulder has been dislocated.

Fractures associated with shoulder dislocations commonly involve the glenoid rim, impression fractures of the humeral head (Hill–Sachs and reverse Hill–Sachs lesions), the greater tuberosity, the humeral neck, and shear injuries of the humeral head. Glenoid and impression fractures of the head are associated with recurrent dislocations but rarely need immediate treatment. Tuberosity fractures usually reduce when the dislocation is reduced and will heal spontaneously. If the residual displacement is more than 3–4 mm, they may cause impingement symptoms and need surgical correction [5]. Shoulder dislocations associated with humeral neck and articular surface fractures are usually treated initially with attempted closed reduction. If successful the fractures are treated individually as described in the next section. If unsuccessful the options are the same as for isolated dislocations.

Chronic Dislocations

Shoulder dislocations presenting late are common in low resource environments and more challenging. The usual definition of "acute" is within 3 weeks of injury [5]. Dislocations seen in this time period will often reduce with closed treatment, although as time goes on more muscle relaxation might be needed, including general anesthesia. A closed reduction can be successful up to 4 weeks, but be gentle and take increased care to avoid fracturing the humerus, especially avoid forced rotation (Fig. 18.3).

Advice from surgeons in developing countries suggests that beyond 3 months, open reduction is extremely difficult and should not be attempted. It is better to begin physical therapy for range of motion and muscle strengthening. The patient will not regain full abduction or forward elevation but will have satisfactory function otherwise as the case illustrates (Box 18.1).

Box 18.1 Case Illustration

A 26-year-old male came to the orthopedic clinic with a chief complaint of inability to use his right upper extremity to reach or perform activities at or above shoulder level. He had injured his shoulder 7 years before and was told later that it was dislocated, but he had not been treated. The right shoulder had an active range of motion of 30° abduction, 40° forward elevation, and full internal and external rotation. This appeared to be performed with minimal discomfort. Elbow and hand function were normal. X-rays showed an anterior glenohumeral dislocation. Although he wanted to have improved "use" of his shoulder, he was employed and stated that pain was not a problem. The clinic staff felt that no further treatment was indicated.

If closed reduction is not possible, the two remaining options are open reduction and early rehabilitation allowing the shoulder to remain dislocated. While many surgical approaches have been described [6, 7], all report difficulty replacing the humeral head into the glenoid and having it stay. Some have used pins through the head into the glenoid to secure the reduction. Most report limited range of motion post-op, while injury to the axillary nerve is common. Results are worse the longer the shoulder has been dislocated.

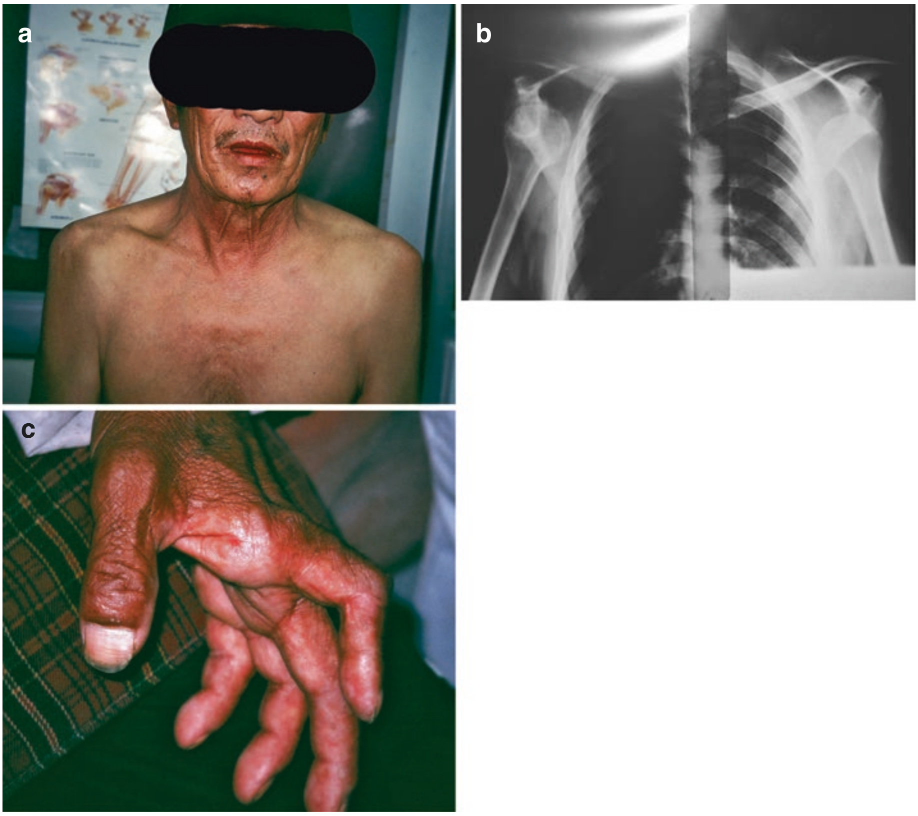

Fig. 18.3 (**a**) This farmer fell out of a tree in his orchard 6 weeks before and sustained right and left anterior shoulder dislocations. (**b**) Shoulder X-rays. He came to the orthopedic clinic because he was having some difficulty doing his farm work due to limited motion, and traditional therapy had not improved the function. He had no pain and therefore no surgery was offered. (**c**) He also had a complex dislocation of his left index MP 8 years previously and had no complaints regarding it. (Courtesy of Dr. Sam Baker)

We advise against simple humeral head resection as a flail shoulder is not functional. Patients with a chronically displaced shoulder usually adapt fairly well from a functional point of view, but if residual pain is truly disabling, two surgical options remain. Arthrodesis is technically challenging if the displacement is long standing. The second option, "shoulder Girdlestone" or Laurence Jones procedure, is a trade-off between pain and weakness/instability but may allow better function (see Chap. 41) (Video of one surgical technique for treatment of chronic dislocation of shoulder for which the authors have no personal experience https://www.vumedi.com/video/surgical-reduction-of-chronic-shoulder-dislocation/).

Proximal Humeral Fractures

Proximal humeral fractures account for about 5% of all fractures and have two peaks of occurrence: high-energy fractures in young adults and low-energy injuries in the elderly [1, 8].

The fracture patterns follow the epiphyseal lines of the greater tuberosity, lesser tuberosity, humeral head, and humeral shaft (Fig. 18.4). The Neer classification system is based on the relative displacement of these four fragments [9]. A displaced fragment is separated by at least 1 cm or angled more than 45°. Fractures become more unstable as the pattern advances from two to three to four parts. Valgus impacted fractures are encountered most frequently in older adults. Though there is often some deformity, they are stable regardless of the number of fracture lines present.

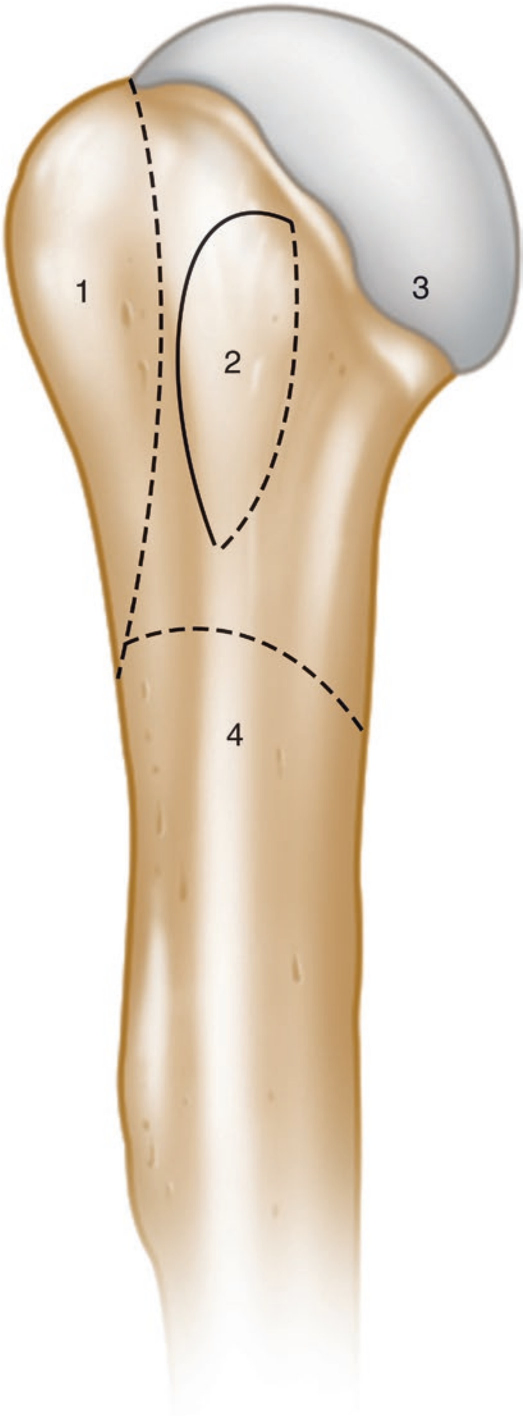

Fig. 18.4 The four major fragments used to classify proximal humeral fractures are *1* greater tuberosity, *2* lesser tuberosity, *3* humeral head, *4* humeral shaft

The majority of proximal humeral fractures are impacted or minimally displaced and will heal with a functional ROM and near normal upper extremity function with closed treatment in a sling and early rehabilitation [8]. Unstable two-, three-, or four-part fractures remain a challenge wherever encountered. Surgical treatment is often considered necessary for these fractures and includes percutaneous pins, suture stabilization, plates and screws, intramedullary rods, humeral head replacement, and total shoulder arthroplasty. Reported complications occur with all of these techniques [1]. In most developing countries, angular blade plates, locking plates, and shoulder prostheses are not available.

The most common choices for treating displaced fractures are percutaneous K-wire pinning; flexible intramedullary rods, such as Rush rods; or cloverleaf buttress plates (Fig. 18.5). Percutaneous pin fixation is best done with plain X-ray or fluoroscopy. If closed reduction is not possible or X-ray is not available, open reduction with multiple pin fixation is a satisfactory option with good results reported. Suture reinforcement is useful to supplement buttress plate fixation when adequate screw purchases are not possible due to comminution or osteoporosis. A figure of eight wire can stabilize two- and three-part fractures especially if heavy suture is unavailable. Displaced humeral head fractures pose a risk for avascular necrosis but the rate decreases if the head retains at least 8 mm of the calcar. Recently described straight lateral approaches to the humeral head with dissection and protection of the axillary nerve have allowed a more direct approach with less forceful retraction of the swollen deltoid and less overall dissection [10] (lateral approach to proximal humerus: youtube.com/watch?v=emQWWQwMEP4).

Humeral Shaft Fractures

Diaphyseal fractures of the humerus account for about 3% of all fractures and occur from high-energy injuries in young adults to low-energy falls in older adults [11]. The simple designation of spi-

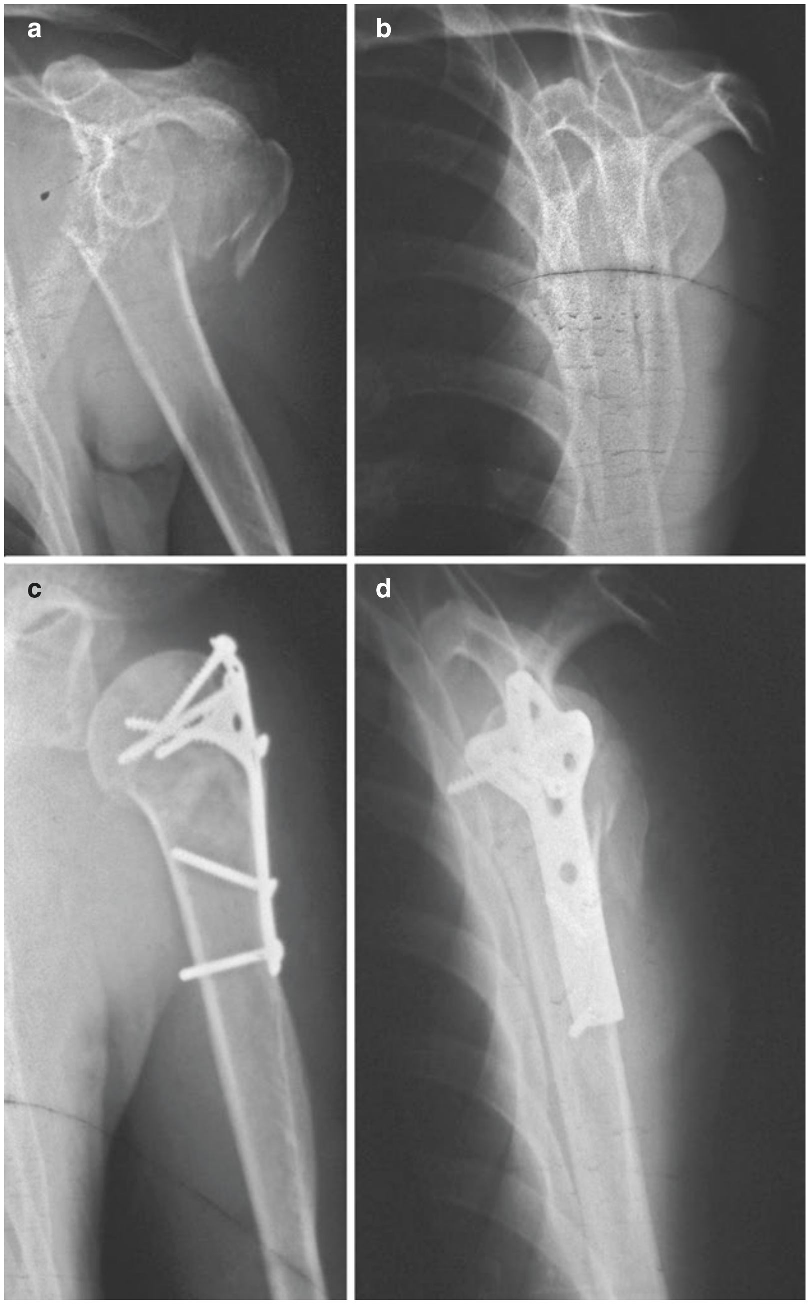

Fig. 18.5 (**a**, **b**) Preoperative X-rays of the right shoulder showing a four-part fracture of the proximal humerus. (**c**, **d**) X-ray taken 4 months after open reduction and application of a buttress plate. The patient had some limitation of external rotation but otherwise full motion. She had symptoms of impingement, which improved after removal of the plate

ral, oblique, transverse, segmental, and comminuted will help guide therapy (Fig. 18.6) [11]. Other considerations include the status of the radial nerve, the presence of an open wound, the type of trauma (penetrating/blunt, high or low energy), the age of the patient, and the associated injuries.

The diagnosis can be suspected clinically from the history and physical examination, but when possible, obtain humerus X-rays in two planes that include the shoulder and elbow. Confirm the radial nerve function initially and during each stage of treatment.

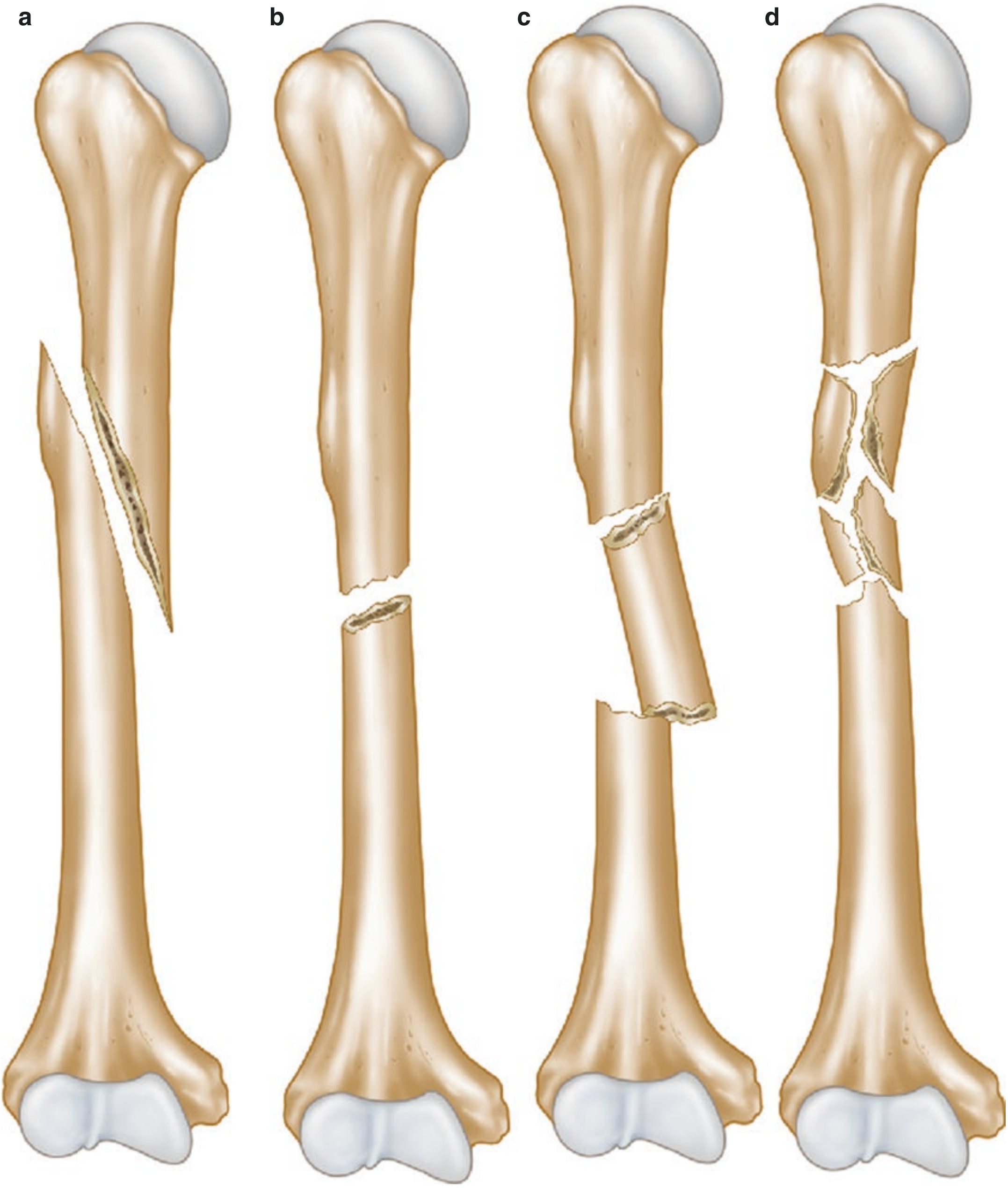

Fig. 18.6 Functional classification of humeral shaft fractures to help with treatment decisions. (**a**) Oblique/spiral, (**b**) transverse, (**c**) segmental, and (**d**) complex comminuted

Standard treatment options include closed management with a functional brace or coaptation splint and surgical treatment with plates and screws, an intramedullary rod, or external fixation [12]. The limits of acceptable deformity are 20° anterior–posterior angulation, 30° varus–valgus angulation, 20° malrotation, and 3–4 cm shortening [11]. The goal of treatment is a solid fracture union within these parameters with a functioning radial nerve.

Treatment with a functional brace following a closed reduction has a reported success greater than 90% in both open and closed fractures [13] (see Appendix 5 for technique of making a functional humeral brace from PVC pipe). Treatment is usually begun with a coaptation splint for 7–10 days followed by an adjustable brace or a cast brace until fracture consolidation, about 12 weeks. The brace can be made from locally available materials or by shortening the coaptation splint. Wrist, elbow, and pendulum exercises are begun when tolerated. The splint needs frequent adjustment to keep it snug, and the patient should remain in an upright or semi-sitting position for 4–6 weeks in order to maintain fracture alignment. Hanging casts rely on gravity for reduction by ligamentotaxis but are often too heavy and too short and have a higher rate of nonunion, so it should be considered a distant alternative to a well-applied coaptation splint.

Stable internal or external fixation is indicated in patients with head trauma, multiple injuries that preclude remaining in a semierect position, vascular injuries, and concomitant fractures of the shoulder or forearm. Rigid plate fixation in a good bone with screws crossing six cortices may have an advantage over locked IM nails of allowing partial early weight bearing [14]. Flexible rods work well but require a compliant patient and possibly external bracing to avoid nonunion (Fig. 18.7) (Various surgical approaches to the humeral shaft—https://www2.aofoundation.org/

Fig. 18.7 Rush rod fixation of a mid-shaft humerus fracture in which the angulation could not be controlled with a coaptation splint. (**a**) Persistent angulation in the splint. (**b**) Postoperative X-ray after Rush rodding

Fig. 18.8 External fixation device used to stabilize a comminuted distal humeral shaft fracture

wps/portal/sur-gery?bone=Humerus&segment=Shaft&showPage=approach).

External fixation is indicated if there are open wounds or as temporary fixation (Figs. 18.8 and 18.9). If the fracture extends near the distal metaphysis, the ex-fix should cross the elbow joint by placing two lateral pins in the humerus and two pins in either the radius or ulna. Proximity of the underlying nerves requires insertion of the pins through small incisions with dissection to the bone and not percutaneously.

Management of radial nerve paralysis related to this fracture is enhanced with electrical studies, but if not available, it is important to make initial and periodic sensory and motor assessments of nerve function. If the nerve is not working when the patient is first seen and surgery is needed either for debridement of an open wound or fracture fixation, explore the nerve during the procedure. If the injury is closed and the nerve is not functioning initially or if function is lost during treatment, place the patient in an extension wrist splint and monitor. Initial signs of functional recovery can be seen by 2 months with complete return expected by 6 months. If there is no neurologic recovery by 3–4 months, consider nerve exploration. Tendon transfers for a nerve that has not returned in 6 months are a good option.

Conclusion

The shoulder and humerus are common sites for injury and often occur not in isolation but in conjunction with injuries of the ipsilateral elbow, forearm, and hand and also as a component of the multiply injured patient. Treatment needs to be prioritized, and strict protocols are not applicable. Emphasis has been placed on simple, safe regimes for areas with scarce resources, but it is assumed that as more complex treatment methods become safely available, they will be employed.

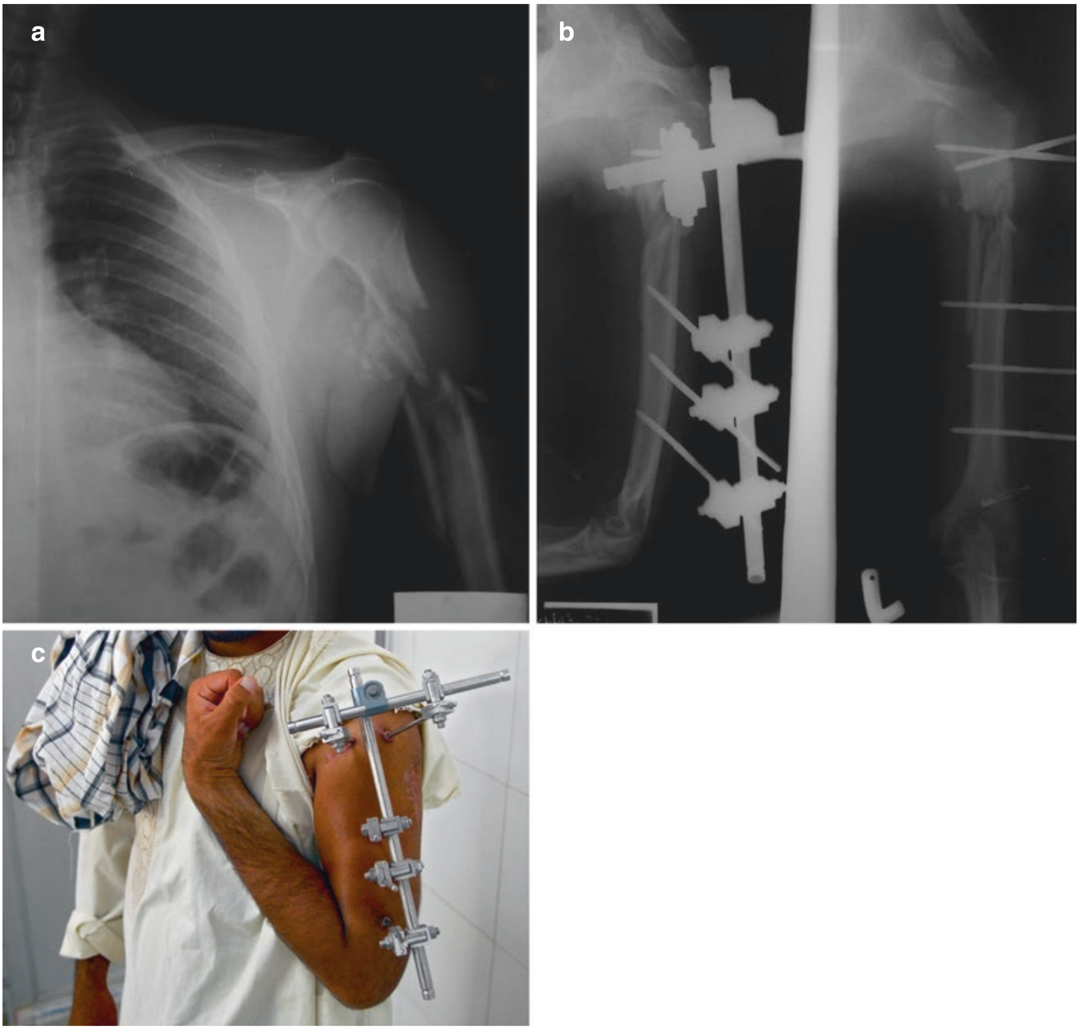

Fig. 18.9 (**a**) X-ray of GSW proximal left humerus. (**b**) X-ray with external fixation. (**c**) Lateral placement of the pins allows near full active elbow flexion

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19 Trauma of the Elbow and Forearm

Robert P. Hoffman and Sonam Dorji

Introduction

The elbow is a fascinating and important joint for proper upper extremity function. Useful elbow motion ranges from −30° extension to 130° flexion with 50° each supination and pronation. Post-injury restoration of function depends on early, progressive range of motion. In low- and middle-income countries (LMIC), old, poorly treated, or untreated elbow trauma is the common presentation. For these, early motion is impossible, and elbow stiffness is the normal end result. With this reality in mind, this chapter will touch on practices and procedures to help surgeons approach and treat some of the more common acute and chronic traumatic problems in the elbow and forearm, with a brief review of heterotopic ossification and inflammatory, degenerative, and post-traumatic elbow arthroses.

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Acute Traumatic Conditions

Dislocations

In austere environments, timing is a challenging issue. If the dislocation is seen acutely, it can be managed as one would in high-resource environments (Video of reduction of acute dislocation https://www.youtube.com/watch?v=A91TWNbSEOQ). Without hinged splints allowing protected motion, the injury may require longer initial immobilization than ideal, but this will produce a stable elbow. If the dislocation is combined with radial head or other fractures, NSIADs can minimize the high risk of heterotopic bone (Fig. 19.1).

Physical therapy will improve the final results, but many patients either live too far away or have trouble following simple instructions. The surgeon can play a vital role if reliable therapy is not available, by taking the time to teach and make sure the patient and his caregivers know what and what not to do.

Fracture/Dislocation: Terrible Triad

This fracture/dislocation—torn collateral ligaments and fractures of the radial head and coronoid process—produces an unstable elbow that is best treated by open reduction and fixation (https://www.orthobullets.com/trauma/1021/ter-

R. A. Gosselin et al. (eds.), *Global Orthopedics*, https://doi.org/10.1007/978-3-030-13290-3_19

Fig. 19.1 (**a**) X-rays of an open posteromedial elbow dislocation. (**b**) The exposed median nerve tented over the trochlea

rible-triad-injury-of-elbow). The results are less than ideal under the best circumstances, and without radial head implants, small headless compression screws, suture anchors, and small surgical instruments, results are compromised. ORIF of the radial head with whatever is available should be attempted. Even if excised later, a damaged radial head provides the necessary acute stability to prevent valgus deformity and distal radioulnar problems. Even without a coronoid fracture, the lateral ulnar collateral ligament may have to be repaired if the elbow remains unstable. The medial collateral ligament rarely needs acute repair, but if torn it is important to save the radial head. Otherwise valgus instability is virtually assured.

Dislocation with Coronoid Fracture

Type I coronoid fractures—avulsions of the tip that do not adversely affect elbow stability—need not be fixed, and dislocations with such fractures need a well-thought-out rehabilitation program to prevent stiffness. Type II fractures, involving approximately 50%, and type III, involving greater than 50% of the coronoid, are usually unstable and require open stabilization (Fig. 19.2). Exposure of the coronoid can be difficult. With a radial head fracture that is deemed fixable, a lateral Kocher interval incision can be used. Once the elbow is reduced and the radial head repaired, stability should be rechecked. If the elbow is stable at 30° flexion, the coronoid need not be repaired. If unstable, the lateral ulnar collateral ligament is taken down from its humeral origin to visualize the joint. If large enough, the coronoid fragment is fixed with a small fragment screw or a suture around or through the fragment and tied on the posterior surface of the olecranon. After coronoid fixation the lateral ulnar collateral ligament can be repaired at its origin with drill holes in the center of the lateral epicondyle.

Fig. 19.2 Lateral view of terrible triad with type I coronoid fracture

For coronoid fractures with a sagittal component or medial extension, fixation with a small plate may be necessary. Without the need for a lateral approach to the radial head, the coronoid can be approached medially. Care must be taken to protect the ulnar nerve and the anterior fibers of the medial collateral ligament.

If the elbow is stable after repair, early motion at 7–10 days will lead to better long-term function than longer immobilization. A removable long arm splint can be used between exercise periods. If the repair is not stable, casting or splinting for 3–4 weeks is necessary. In this situation, stiffness is likely.

Fractures About the Elbow

Distal Humerus Fractures

In the developing world, these fractures can be a real test of the abilities and judgment of the surgeon. Basic principles used in resource-rich environments should be applied as circumstances allow. Most locations will have a small fragment set. Reconstruction plates placed in a 90°/90° fashion or parallel plates at 180° are the best choice, and DC plates contoured to fit are the second choice. Two semi-tubular plates stacked together to improve the implants' strength will also work. For isolated one-column fractures, a single plate may be adequate if screw fixation is secure (Fig. 19.3). For fractures of both columns and intra-articular fractures, a 90°/90° plate configuration—lateral column plate placed posteriorly and medial column plate placed medially—is recommended. Parallel plating with the lateral plate along the lateral epicondyle is also acceptable. In this case the screws from both sides can interlock and provide more rigid fixation, especially in comminuted intra-articular fractures. In general, before plates are applied, the intra-articular pieces should be reduced as best as possible with either K-wires or cannulated screws. The medial plate is contoured to the medial supracondylar ridge and may extend as distal as the ulnar groove. Identify and mobilize the ulnar nerve early. If the nerve ends up lying over

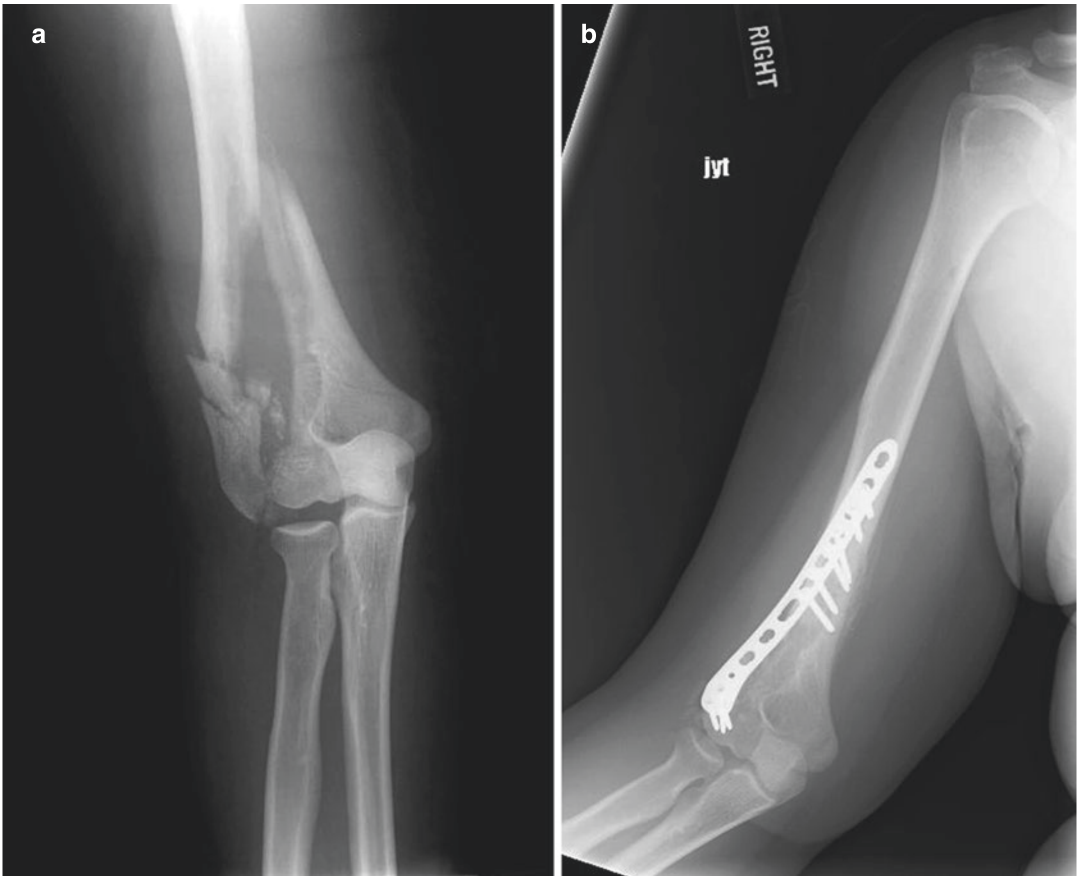

Fig. 19.3 (**a**) Comminuted lateral column fracture with high medial column involvement. (**b**) Fracture can be well fixed with only a lateral column plate as long as adequate inter-fragmentary fixation is used for the articular surface and the large medial condylar fragment

hardware without soft tissue interposition, transposition may be indicated. The preferred technique is the simplest: subcutaneous anterior transposition, securing the position with a couple of nonrestrictive sutures or fascial slings in the subdermalfascial plane.

In the 90°/90° plate configuration, the lateral plate is applied posteriorly and contoured so its distal end abuts the articular surface of the capitellum. Intra-articular fractures usually require an olecranon osteotomy for adequate exposure. Other than accurately reconstructing the articular components of the joint, it is important, especially in very comminuted fractures, to maintain the proper width of the distal humerus (Fig. 19.4) (Video of distal humerus plating. https://www.youtube.com/watch?v=gBfg8Dfbi24).

If an olecranon osteotomy is performed for better exposure of the distal humerus, an intra-articular chevron or straight osteotomy gives good visualization of the humeral articular surface. Bicortical drill holes are made in the olecranon at the proposed osteotomy, taking care not to damage the distal humerus articular cartilage. An osteotome or power saw connects the holes in an incomplete cut, allowing the far cortex to be cracked open, minimizing damage to the articular cartilage. The osteotomy is repaired using a tension band technique supplemented with either a pre-drilled 6.5 cancellous screw and washer or two parallel K-wires.

Over the years, many of these fractures have been fixed with only K-wires if either surgeon skill or equipment is lacking. This is a risky tech-

Fig. 19.4 (**a**) AP x-ray of a low bicondylar distal humeral fracture. (**b**) Lateral of same. (**c**) Postoperative AP x-ray. Note the 90°/90° position of the plates with the lateral plate posterior and the medial plate contoured around the medial epicondyle. Non-locking, contoured, reconstruction plates were used here. Note the inter-fragmentary screw used to fix the intra-articular fragments. The olecranon osteotomy was fixed with K-wires and tension band wiring. (**d**) Lateral x-ray view emphasizes the 90°/90° plate placement

nique since loss of fixation, early and late stiffness, infection, reoperation to remove motion-obstructing pins, nonunion, and post-traumatic arthritis are common results (Fig. 19.5). In severely comminuted distal humerus fractures, the nonoperative "bag of bones" approach may give better results while limiting iatrogenic disaster. This is especially useful in elderly patients with highly comminuted osteopenic fractures. This can be accomplished using an olecranon pin or winged screw overhead or lateral traction if the patient and hospital are geared for lengthy stays and such traction setups are available. Traction is kept for 3–4 weeks, allowing early elbow ROM in traction as tolerated. When the fracture is sticky, traction is discontinued, and a splint or cast is applied, until there is enough stability for unprotected ROM (Fig. 19.6).

For patients who cannot tolerate or afford bed rest, the elbow can be stabilized in a back slab for

Fig. 19.5 (**a**) X-ray of comminuted intra-articular distal humerus fracture. (**b**) X-rays show early, inadequate proximal callus in the face of unstable fixation with K-wires and cerclage wires. (**c**) The end result is nonunion with more motion at the nonunion than the elbow

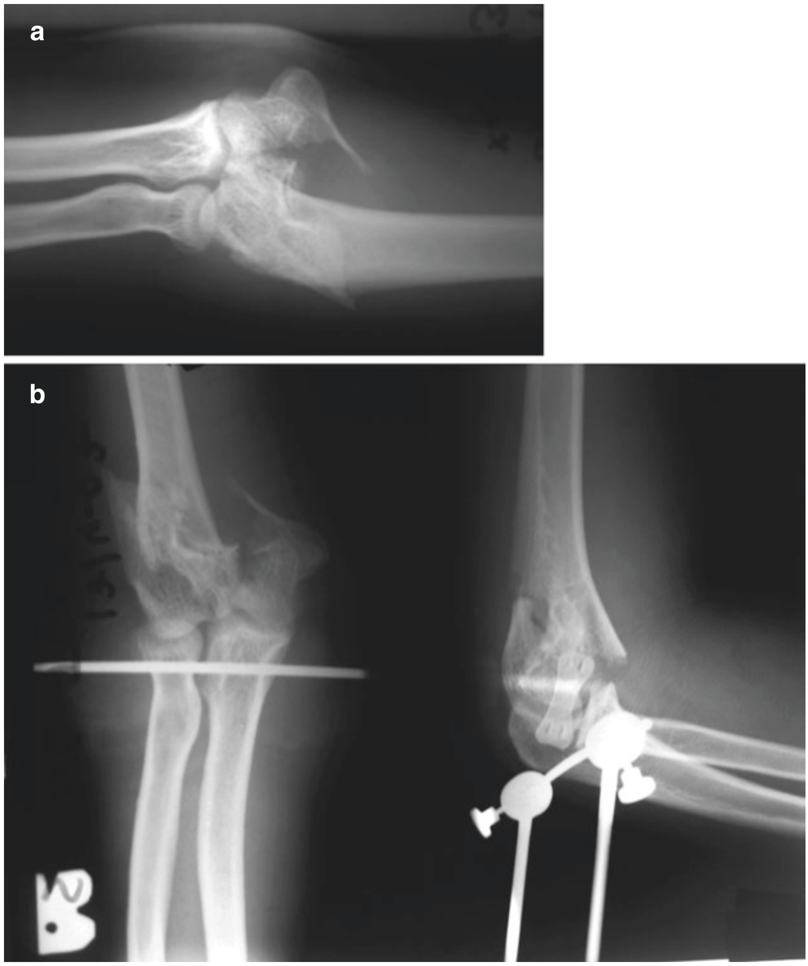

Fig. 19.6 (**a**) X-ray of comminuted, bicondylar, intra-articular fracture of the distal humerus. (**b**) Olecranon pin is used for traction in a nonoperative "bag of bones" treatment

7–10 days until gentle active and passive range of motion is initiated, hoping eventually for a painless nonunion. The elbow is very prone to stiffness even in the face of minor injuries and short immobilization times. Whatever technique is selected to treat these injuries, the surgeon should aim for motion as early as possible.

Capitellum

With a large capitellum fragment, ORIF with a headless screw is ideal. Burying a headed screw or fixation from the posterior aspect of the lateral column is a viable alternative. Temporary K-wire fixation is a mechanically poor alternative and requires at least 3 weeks immobilization in neutral position before the wires can be removed. In a worst-case scenario, excision of the capitellum may be the only option. The results of this approach are mixed, just as those with excision of the radial head. Proximal migration of the radius will produce pain in the wrist with either capitellar or radial head excision in about one-third of patients.

Radial Head

Mason type 1 and 2 radial head fractures can be treated with nonoperative management. Radial head excision with prosthetic replacement for fractures with comminution greater than four components or inability to achieve an accurate articular reduction is the general recommendation (Mason type III) (Fig. 19.7). Without radial head replacements, ORIF, even if not perfect, may be a better option using buried K-wires, intraosseous wiring, or intraosseous sutures. Some authors have reported good results with late excision of Mason type IV fractures (any radial head fracture combined with an elbow dislocation), and this may be a reasonable approach for certain situations. Take care to examine the wrist for pain in the face of a radial head injury—the Essex–Lopresti lesion—as the distal radioulnar joint may be disrupted. When there is associated medial instability, the radial head should be reconstructed as best as possible to serve as a spacer, to prevent valgus displacement while the soft tissues are healing. It can be excised later. The only caveat to this is if a fragment of the radial head is widely displaced, it should be excised early, but the rest of the radial head, even if fractured, can be left in place and excised later if necessary (https://www.vumedi.com/video/orif-radial-neck-fracture/).

Olecranon

Non-comminuted olecranon fractures can usually be treated with standard tension band technique as detailed above. In comminuted fractures, inter-fragmentary fixation and neutralization plating with a small fragment reconstruction or DC plate are preferred, taking care that the elbow joint volume is maintained.

Radius and Ulna Fractures

Shaft fractures of the radius and ulna are approached in the same fashion whether in high- or low-income environments. X-rays need to show the elbow and wrist to rule out commonly associated injuries. Small fragment plates are usually available, and results with these in adults are far superior than other treatments in achieving fracture alignment, bone length, and preservation of the interosseous space. In the event that plates and screws are unavailable, either closed reduction and a long arm cast, percutaneous or open fracture fixation with one or two K-wires, or IM K-wires can be used.

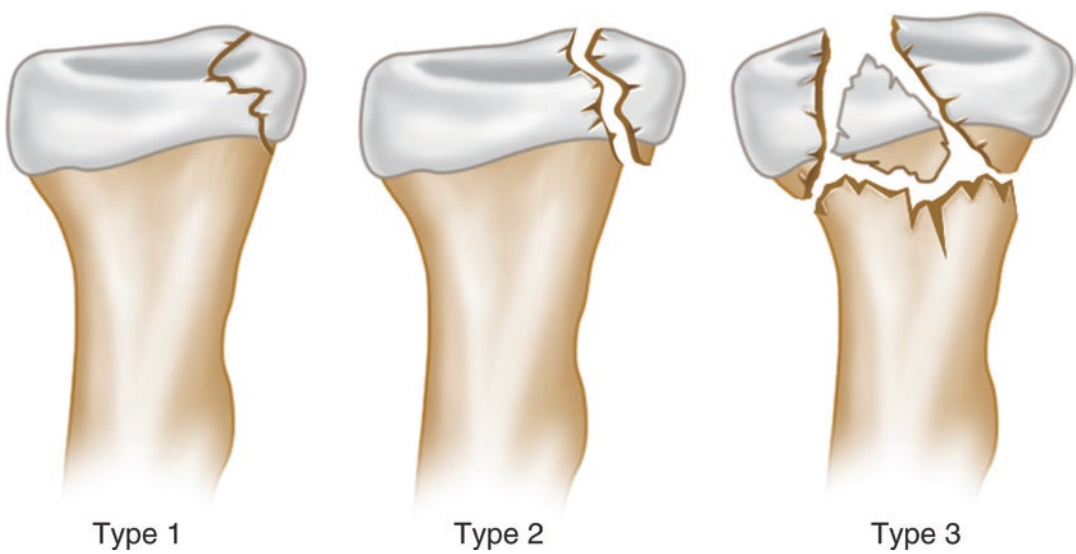

Fig. 19.7 Mason classification of radial head fractures. Type IV is any radial head fracture combined with an elbow dislocation

IM nailing with small Ender nails, Steinmann pins, or stacked K-wires requires open reduction if there is no C-arm or the fracture is old. This technique is usually only successful in controlling length and axial alignment while providing no rotational stability. The radius is nailed starting from the styloid, Lister's tubercle, or, more medially, the ulna from the olecranon tip. These wiring techniques are less than ideal and should be used only when plate and screw internal fixation is not available. Post-op, an above elbow cast with interosseous molding is necessary. This can be converted to a Munster cast at 3 weeks (see Chap. 13). In fractures proximal to the insertion of the pronator teres, the forearm should be immobilized in supination to accommodate the position of the proximal fragment. In fractures distal to the pronator teres insertion, the forearm is better aligned in neutral rotation (Fig. 19.8).

For plating, the ulna can be approached along its entire length on the subcutaneous border. Plates can usually be placed beneath the flexor carpi ulnaris making plate irritation and the need for later removal less likely. For radial fractures in the distal two-third of the shaft, the volar Henry approach is the easiest and safest. For more proximal fractures, there is disagreement as to whether the dorsal Thompson approach, with its potential for posterior interosseous nerve injury, or the Henry approach, with many vessels in the way and a much deeper location of the radius, is the better choice. The surgeon's training and comfort level will make the decision (https://www2.aofoundation.org/wps/portal/surgery?bone=Radius&segment=Shaft&showPage=approach).

Many forearm fractures will be seen late. Six weeks is not uncommon. Even at several months, it is often possible to find the callus and take down a potential malunion before a formal osteotomy is required. In these cases, with rounded fracture ends, some shortening may be required of both bones in order to obtain good coaptation.

Isolated ulnar shaft fractures such as a "night stick" fracture can often be successfully treated with a short arm cast or locally made coaptation

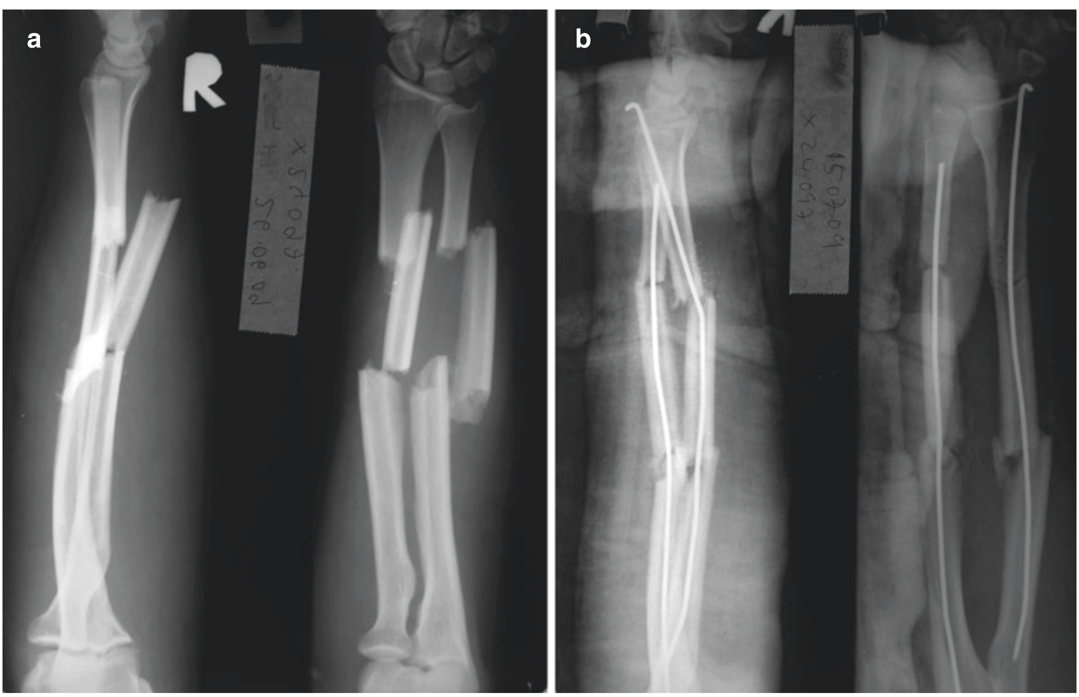

Fig. 19.8 (**a**) X-rays of a segmental both-bone forearm fracture. (**b**) Repaired with thin Rush rods opening the fracture site

splints. As long as a good interosseous space is maintained, results are usually acceptable.

Monteggia and Galeazzi fracture/dislocations require anatomic reduction with plate fixation for good results in adults. Without anatomic reduction of a Monteggia fracture, radial head subluxation or dislocation may persist, and long-term results will be poor (Fig. 19.9). If Galeazzi fractures are not reduced anatomically and there is disruption in the distal radioulnar ligaments, a poor result can be expected. The most reliable treatment is plating the radial fracture and testing stability of the distal radioulnar joint (DRUJ) in supination, where the DRUJ is the tightest. If stable, cast in supination for 6 weeks. If the DRUJ is still unstable in supination, reduce the joint and

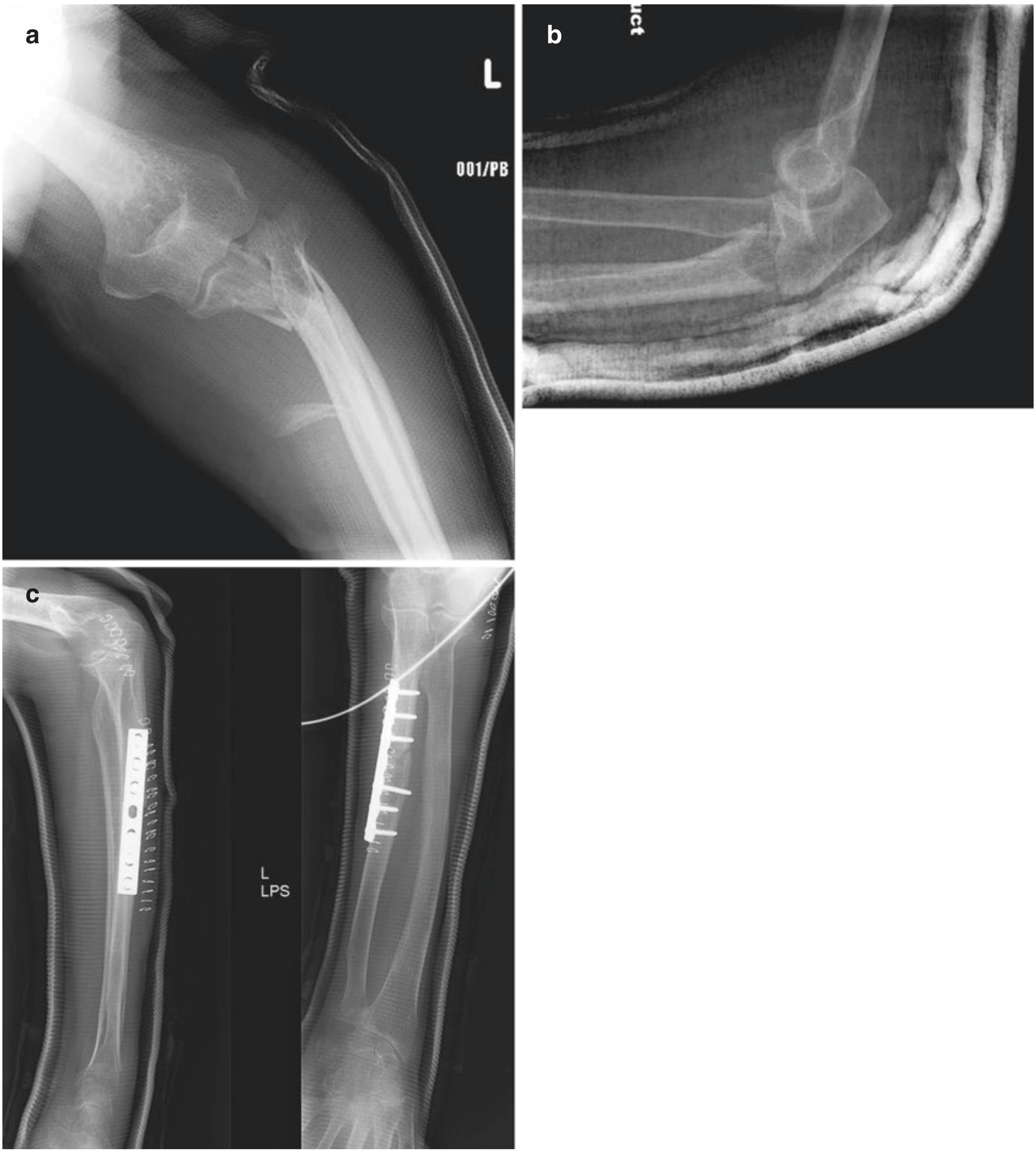

Fig. 19.9 (**a**) AP x-ray of a Monteggia fracture with clear dislocation of radial head. (**b**) Lateral view; (**c**) on this x-ray of a different patient with a Monteggia fracture, the radial head is well reduced after plating the ulna (non-locking DC plates or reconstruction plates can be used in place of the locking plate shown here)

transfix it with a 1.6 mm K-wire for 6 weeks. When pinning the DRUJ, it is safest to immobilize forearm rotation with either a long arm cast or a Muenster cast, leading to pin breakage and subsequent difficulty in removal.

Galeazzi fractures are often initially placed in ill-fitting below-elbow casts by technicians, nurses, or physios who recognize only the single bone fracture and not the complex injury pattern. A K deformity with nonunion of the radius is common, requiring ORIF, occasionally with bone graft.

Ruptured Distal Biceps Tendon

A ruptured distal biceps tendon will compromise the strength of supination more than flexion. In the developing world, these can affect a patient's ability to do heavy labor but will not be incapacitating. Careful thought should be given whether repair is necessary. If repair is chosen, suture anchors are typically not available, requiring a two incision technique, Boyd–Anderson. The incidence of heterotopic bone is high in this approach during ulnar exposure when passing the end of the biceps tendon posteriorly to the second incision. Thought should be given to the use of indomethacin to prevent heterotopic ossification using this Boyd–Anderson technique. (https://www.vumedi.com/video/distal-biceps-repair-anatomy-approaches-complications/; video of two incision technique of repair https://www.vumedi.com/video/two-incision-distal-biceps-repair-2/).

Compartment Syndrome

Forearm compartment syndrome can be a devastating complication of supracondylar humerus fractures, radius and ulna fractures, or any upper extremity crush injury. The rate of muscle death is proportional to the compartment pressure and duration. A high index of suspicion and timely volar and dorsal compartment releases are necessary to prevent catastrophic complications. In the developing world, many potential compartment syndromes will arrive at the hospital days after the original injury. If loss of active muscle function or numbness has been present for over 24–48 h, one can assume that the muscles are dead and will not respond to fasciotomy. Ill-advised late fasciotomies almost always lead to poor wound healing, infection, and even late amputation, making it safer to leave the situation alone and treat any contractures that develop on an elective basis. This is particularly true of crush injuries seen in natural disasters. Splinting acute Volkmann's contracture in as much wrist and finger extension as tolerated can often give a reasonably function hand if done early and continued for 6–9 months. Physiotherapy combined with splinting will generally improve long-term results (Video of acute forearm compartment decompression: https://vimeopro.com/orthotraumaassn/2015-surgical-technique-videos/video/187066285).

Chronic Traumatic Conditions

Old Dislocations

In the developing world, many elbow dislocations will either be untreated or poorly treated. Local bone setters will often place the elbow in full extension and splint it for weeks. When presented with an old dislocation or subluxation greater than 1 month, several important questions regarding treatment need to be asked:

1. Will the soft tissues allow a reduction even with a major ligamentous release?
2. Is pain a factor? Some old, chronic dislocations may have limited motion but retain stability and are minimally painful, especially when in the non-dominant extremity. In this situation, consider whether overall function can be improved, i.e., making the risk of the procedure worth the benefit.
3. If the elbow can be reduced, how will it be maintained? Is a hinged external fixator available? Usually not. A static ex-fix or a large Steinmann pin through the olecranon into the humerus may be the only options.
4. Chronic dislocations require much therapy to regain useful function. Is it available and will the patient cooperate?

All these potential pitfalls make this a difficult problem to treat. In general, an open reduction may be attempted if the above issues are found to be acceptable (video of surgical technique of chronic elbow dislocation: https://www.vumedi.com/video/open-reduction-of-a-chronic-elbow-dislocation/. PDF: https://www.researchgate.net/publication/321763201_Surgical_Treatment_of_Chronic_Elbow_Dislocation_Allowing_Early_Range_of_Motion_Operative_Technique_and_Clinical_Results).

Stiffness

Given the paucity of physical therapy, late presentation, poor patient compliance, and long periods of immobilization, stiffness is a problem that is often the rule, not the exception. As with chronic dislocations, great care must be taken when making a decision to operate. Even with significant stiffness, elbow function can be reasonably good. A functional range of motion is considered to be −30° extension to 130° flexion and 50° each of supination and pronation. This is ideal, but less motion can still be useful, especially with normal shoulder and wrist/hand function. It takes about 110° of elbow flexion—with a mobile wrist—for the fingers to reach the mouth.

In the developed world, stiffness is often dealt with arthroscopically, but lack of equipment and experience makes this technique virtually absent in austere environments. If open release is selected, intense and frequent therapy must be available to maximize postoperative range of motion. Static, progressive splinting can also help to regain motion after an extensive elbow release.

Heterotopic Bone and Synostosis

Ulnohumeral Synostosis

Heterotopic ossification (HO), with or without synostosis, is a significant and not rare complication of elbow injury. Any fracture around the elbow can produce HO, but fracture dislocations have the highest incidence, approaching 35%. With heterotopic ossification and stiffness, all of the previously mentioned problems surrounding surgical release apply. Any serious fracture around the elbow, accompanied by a head injury, increases the chances of HO. A localized excision for an isolated HO is often an effective treatment. The distal humerus, coronoid, and tip of olecranon are the most common locations of HO. All of these can usually be reached through an extended lateral approach. One needs to take care to protect the lateral ulnar collateral ligament. It is easily identified, and an approach to the tip of the olecranon posterior to the ligament is straightforward. The anterior part of the elbow and coronoid can be approached anterior to the ligament, so it is often unnecessary to take it down. To release the lateral collateral ligament from its humeral origin, anatomic repair through drills holes is necessary. Postoperative therapy is critical to maintain the range obtained at surgery.

In the case of a formal synostosis, the same approach can be used, but more aggressive excision of bone is often needed.

In the face of HO with or without synostosis, one should consider prevention of recurrence. Radiation therapy is the most predictable method (one dose, 750 cgy) with NSAIDs, the only other proven preventive therapy. Indomethacin is the gold standard, but other NSAIDs can be effective. Determine preoperatively if the patient has any contraindications to such drugs. If one of these two methods cannot be employed, recurrence and failure are expected.

Radioulnar Synostosis

Treatment of radioulnar HO and synostosis follows the same principles as ulnohumeral HO. It is difficult on plain radiographs to determine the location and extent of the HO. Without CT, additional plain films of the forearm in various oblique positions may be necessary to adequately determine the extent and best approach for excision. A posterior approach between the ulna and radius is usually adequate. When very proximal HO causing synostosis cannot be removed, excision of a 1 cm segment of radius distal to the synostosis is a good alternative. This may produce instability but can often restore a functional arc of rotation.

Arthritis

Inflammatory Arthritis

The most common inflammatory arthritis globally is rheumatoid arthritis. In the developing world, medical management is often inadequate or absent. As total elbow replacement is not an option, the mainstay of surgical treatment will be radial head excision and possibly synovectomy. Radial head excision is straightforward, and the results usually justify the risks. Synovectomy should be considered carefully, as intensive therapy along with a compliant patient is needed for a satisfactory result.

Post-traumatic Arthritis and Osteoarthritis

In the elbow, these two conditions have similar presentations, and treatment options for one can often be applied to the other. Without the aid of the arthroscope, surgical approaches will be open. If conservative measures fail, careful consideration of functional needs must be done before undertaking this route. Stiffness often accompanies arthritis, and the concerns regarding stiffness mentioned above need to be answered before attempting any surgery. The most common procedures are debridement, removal of loose bodies, excision of impinging spurs, and possibly radial head excision. As in other problems with the radial head, the risks of wrist pain after excision must be weighed. In chronic radial head excisions, around 30% of patients will have some degree of wrist pain. Salvage procedures for inflammatory, post-traumatic, and osteoarthritis are considered in Chap. 41.

Infection

Penetrating injuries, hematogenous spread, and surgery are common causes of elbow infections. In LMIC, bacterial cultures and sensitivities can be misleading, imprecise, or not available. In other regards, this is one area where a similar approach for all economic and resource levels can be applied, using standard techniques of open irrigation and debridement. A lateral approach to the elbow through a small Kocher incision is usually sufficient to wash out a joint infection. In the presence of osteomyelitis, a more extensive approach is required. Repeat washouts, debridement of avascular bone and cartilage, and appropriate antibiotics are the hallmark of treatment.

Acute osteomyelitis in either the radius or ulna requires long-term intravenous antibiotics with adequate debridement of all dead bone, including shortening of one or both bones. Shortening can produce weakness of the extrinsic muscles crossing the wrist joint, but this is often an acceptable trade-off in the face of chronic osteomyelitis with or without nonunion (Fig. 19.10). (See Chap. 31 for treatment of chronic osteomyelitis.)

Salvage/Reconstructive Procedures

Chronic proximal radial dislocations are challenging. In general, pain is the main indication for surgical treatment, typically radial head excision. In the absence of pain, poor motion is usually not improved with radial head excision.

For chronic dislocations of the ulnar head, disabling pain is the indication for shortening the distal ulna with plate fixation and immobilization in supination. Excision of the distal ulna, Darrach procedure, gives poorer functional results than an osteotomy with shortening and should be considered only where internal fixation is not possible.

Other salvage procedures exist for a painful dislocated ulnar head such as the Suave–Kapandji or the Baldwin procedures. In these the ulna is osteotomized just proximal to the DRUJ (leaving around 2–2.5 cm of distal ulna). A piece of ulna around 1.3 cm is removed proximal to the first osteotomy. One can either leave the distal ulnar head free floating (Baldwin procedure) or reduce it, remove cartilage on both sides of the DRUJ, and fuse the ulnar head to the sigmoid notch with two screws (preferably) or K-wires. In any of these three salvage procedures, the main complication is instability of the proximal ulnar stump. Moving the pronator quadratus origin from the volar to the dorsal side of the distal ulna can help as well as using a distally based slip of ECU tendon.

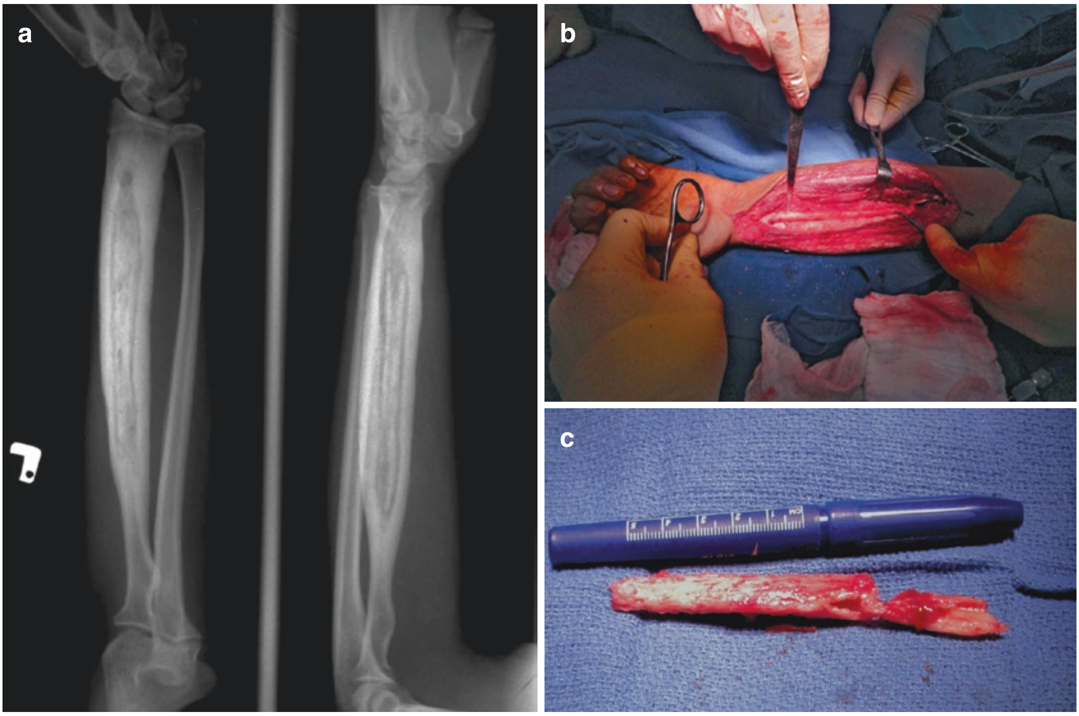

Fig. 19.10 (**a**) Large sequestrum of radius surrounded by newly formed involucrum. (**b**) Large intraosseous window was needed to remove entire sequestrum and residual dead bone within the involucrum. (**c**) The excised sequestrum

For patients with severe elbow pain—usually the result of post-traumatic arthritis—few options exist. In a small number of patients, isolated radial head excision for lateral compartment involvement may be helpful. Remember to consider the possible morbidity due to proximal radial migration and its potential for secondary wrist pain. The only other reasonable alternatives may be interposition arthroplasty or arthrodesis, as described in Chap. 41.

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20 Trauma of the Hand and Wrist

Michelle Foltz and Robert Derkash

Introduction

Two major factors account for the increase in the number of hand and wrist injuries in austere settings: (1) the recent, rapid increase in motorization and mechanization in populations for which safety measures are unrecognized, nonexistent, or ignored and (2) increased longevity that has increased the number of fragility fractures [1].

Traditionally, the majority of these injuries have been treated nonoperatively. Using proper casting and splinting techniques (see Chap. 13) in conjunction with knowledge of the patient's needs and the natural history of the injury while paying attention to detail and follow-up, a surgeon should, in most cases, expect decent results with what are considered low-tech solutions.

General Considerations

Edema is a major problem in all hand and wrist injuries, and preventing it is best accomplished if injuries are seen and treated early and the affected part elevated (N.B: a sling holding the hand and wrist at waist level is not elevation). After reduction and splinting or casting, explain to the patient and family the need for elevation by holding the arm at the elbow so the injured part is above the heart or resting the forearm on top of the head.

A length of tubular stockinette is a useful elevator, but make sure it is not used as a sling. If the patient is admitted, the elevation order needs to be specific and the patient checked in the ward to make sure it is carried out. Elevation can be done using an IV pole, pillows, or folded garments. Range of motion (ROM) within the limits of the splint or cast accompanies elevation as an important edema reduction measure. Make sure the patient can demonstrate a full range of motion, preferably active, but passive will still help. Give the patient and family a specific number of times each day to do the exercises and for how long (Fig. 20.1). Many cultures use massage in traditional treatments, and patients and family are often receptive to edema reduction massage in both the acute and rehabilitation stages.

Rings, bracelets, and armbands are common jewelry and need to be removed after any upper extremity injury. It is unlikely one will find a ring cutter, and sometimes the only instrument is a bolt cutter. In many cultures, religious strings or braids are worn around an extremity. Patients usually object to their removal. Local staff can help explain the need for removal and the patients usually comply, especially if the talisman is retied around the cast.

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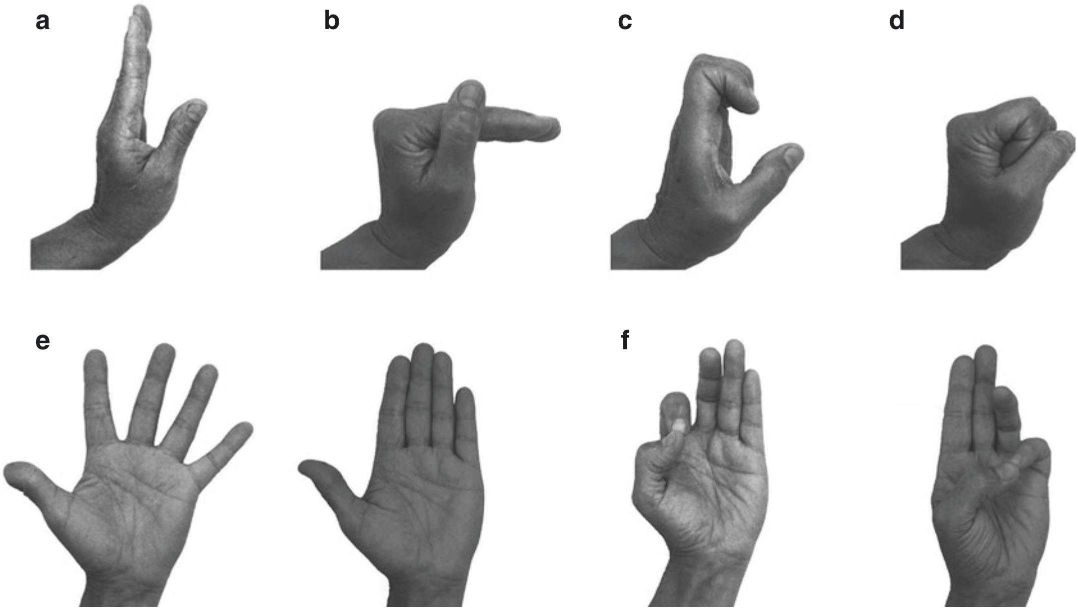

Fig. 20.1 Useful active or passive exercises to teach a patient and his family after hand or wrist injury for ROM and edema reduction. (**a**) Fully extend MP and IP joints. (**b**) Flex MP joints with IP joints extended. (**c**) Extend MP joints with IP joints flexed. (**d**) Make a fist. (**e**) Abduct and adduct fingers. (**f**) Touch thumb to tips of fingers

One of the major drawbacks to nonoperative treatment is the need for frequent early checks to determine the continued proper position of the fracture or adjustment of the immobilization as swelling subsides. For patients who live far from the hospital and for whom lengthy inpatient treatment is not possible, fracture reduction with pinning may be a more conservative approach than simply reduction and casting.

The good outcomes hand and upper extremity surgeons enjoy in high-resource countries depend in large part on hand therapists. With few therapists in developing countries, the surgeon must take on this added role. The surgeon needs to think creatively about how to solve the immediate problems for the patient's advantage.

Equipment and Instruments

Pneumatic Tourniquet

Check if one is present and is the right size for upper extremity work and functions. Esmarch bandages are often used both to exsanguinate and to wrap proximally as tourniquets. They should be used with extreme caution as they can cause severe nerve injury as there is no control over the pressure applied.

Finger Traps

If not available, a simple long gauze made into a "rope" and looped around two fingers with a counterweight on the upper arm substitutes well (Fig. 20.2).

C-Arm

The presence of one in the operating theater does not mean it functions. Assess the quality of the image before planning cases that are dependent on fluoroscopy. Make sure lead protection is available for everyone in the room.

Hand Instruments

Make sure suitable small instruments are available and that they function, e.g., the tips of the forceps meet and the tenotomy scissors actually

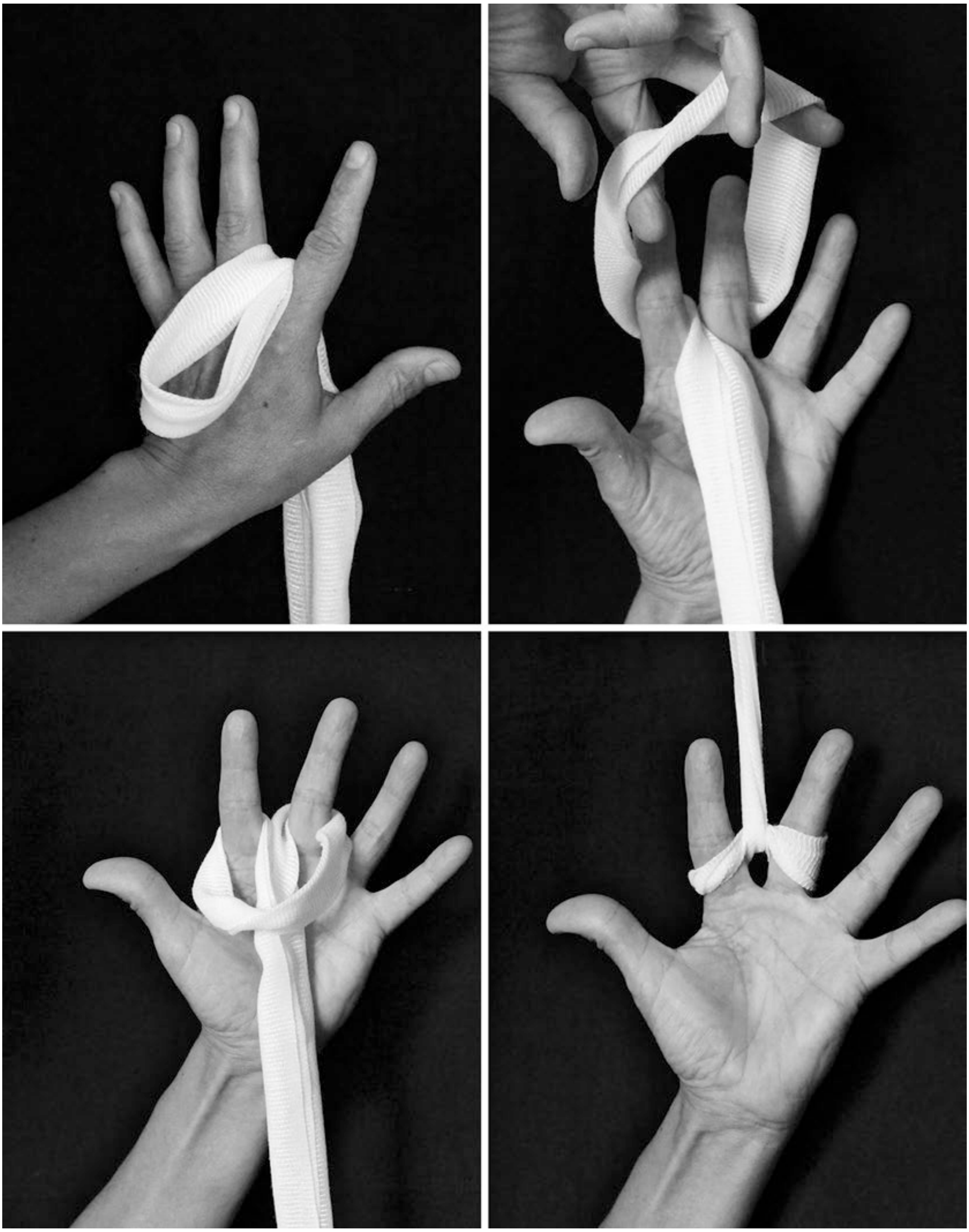

Fig. 20.2 Makeshift elevator made of Kerlix or long bandage gauze to assist in fracture reduction and casting

cut. Hospital staff are often reluctant to discard unusable instruments, knowing they won't be replaced, and return them in the instrument tray for "completeness."

K-Wires

Hospitals often buy K-wires in long lengths, allowing surgeons to cut off what they need. When cut with a dull pin cutter and the incomplete cut is repeatedly worked to complete the cut, the pin is generally out of true and has a burr at the end. Check the size, trueness, and tip points of K-wires before starting a case.

Power Drills

These are expensive and rarely present or are broken or have no wire driver attachment. Sometimes the chuck only accepts large pins. It is thought by some staff that the bones in the hand are small, making power unnecessary. A manual drill is difficult for someone used to working only with power, especially when trying to pin and, at the same time, hold small bone fragments in position. A Jacobs Chuck on a T handle may be more useful.

Lead Hand

Most hospitals in low-resource countries have workshops where a sheet of lead can be cut to make a lead hand or one can be made in the local bazaar.

Upper Extremity Injury with Tendon or Nerve Involvement

If appropriate sutures, instruments, or expertise are not present to repair injured tendons or nerves, it is best to clean the wound, loosely close the skin, and apply a splint in the functional position to avoid further injury and instructions for elevation and passive ROM of the fingers. These repairs can be completed weeks later with good results if there is no infection and the soft tissues are stable. Poor, inadequate, or overly aggressive initial treatments can make a functional outcome impossible.

If one is comfortable repairing tendons and nerves and has the equipment, do not be heroic. Weigh the risks of equipment challenges and availability of hand therapy against hope for good outcome and be realistic. With multiple flexor tendon and nerve injuries, such as a deep slash or cut across the volar wrist, concentrate on repairing the flexor pollicis longus, one wrist flexor, the profundus tendons, and the median nerve. A modified Kessler core suture is recommended for the tendons (video of flexor tendon repair: https://www.searchencrypt.com/videos?eq=E8pos4cXhw4EWpdqVsYE4KaiYpUSRSJWdSpWY7T%2B6x4sOPlD2o3pLr2p2aubL0va). The nerve can be sutured with an epineural repair. Tendon repair distal to the distal palmar crease is not recommended for the inexperienced. Splint with a dorsal plaster of Paris slab that extends beyond the tips of the fingers (include the thumb if involved) with the wrist in 15–20° palmar flexion, the MPs at 45–50° flexion, and the IPs extended. Unless trained physiotherapists are available, it is usually best to splint patients for 4–6 weeks post-repair. Only in carefully selected patients is early motion a good option.

Lacerations and injuries of the extensor tendons across the phalanges where the tendons have thinned and broadened into the intricate extensor hood are difficult to suture. In crush or avulsion injuries, whole areas of the hood may be missing which may require flap coverage. The extensor tendons over the metacarpals and proximally in the forearm are more discrete and can be repaired with either a figure of eight suture or a Kessler-type suture. With loss of extensor tendon continuity proximal to the MP joints that cannot be bridged, it may be possible to reattach the cut distal end of the tendon to an adjacent intact tendon or mobilize one of the proprius tendons as a graft. Postoperative splinting is with the wrist in 30–40° dorsiflexion and MPs in slight flexion and PIP in extension for 4 weeks. Take care to leave intact the dorsal retinaculum to prevent tendon bow stringing.

Fractures of the Distal Radius and Ulna

Colles-type fractures in which the distal fragment is dorsally displaced with apex volar angulation can usually be treated with closed reduction. The Charnley dorsal-radial splint controls both the dorsal and radial deformities (Fig. 20.3). It can be

Fig. 20.3 Dorsal-radial splint. (**a**, **b**) X-ray of distal radius fragility fracture. (**c**) Outline of proposed splint on a 6″ wide plaster slab. This is faced with cotton and can be used for either left or right injuries. (**d**) Splint applied on the dorsal and radial sides of the forearm and wrist and (**e**) wrapped with a bandage, which can be resecured and tightened as swelling subsides

Fig. 20.3 (continued)

used as part of a sugar tongs or a below-elbow splint throughout the 6–8 weeks of treatment, by periodically adjusting the bandages as swelling decreases, or it can be converted into a circumferential POP (plaster of Paris). It is especially useful in elderly patients whose loose skin makes edema problematic.

Unstable fractures or those that lose reduction may benefit from percutaneous pinning. Intraoperative C-arm control helps with pin placement, but two-part extra-articular fractures can be pinned without C-arm using the Kapandji technique of intra-focal pinning. A small dorsal-radial incision allows fracture identification. One or two 0.62 K-wires are introduced into the fracture so they both reduce the fracture and dorsally buttress the distal fragment to hold the reduction. Once the K-wire is placed into the fracture, it can be drilled or tapped into the metaphyseal bone and cortex of the proximal fragment. If percutaneous pins are supported with a circumferential POP, ensure that the pin-skin interface is well padded and the pins do not press directly on the skin. Extending the plaster over the thumb MP joint prevents irritation due to thumb motion near a radial pin.

A wrist-spanning external fixator can be used to maintain alignment and length, with or without percutaneous pinning of the fracture. Pins and plaster can produce similar results as an ex-fix but without the ease of future adjustment. For reducing and fixing comminuted intra-articular distal radius fractures, a C-arm is necessary for percutaneous technique and is helpful for open reduction, but not mandatory.

Smith-type fractures—apex dorsal angulation—can usually be held in a POP with volar distal molding, taking care that no pressure is placed along the median nerve. Adding a short thumb spica to the cast will give a broader molding platform to control the distal fragment. A 0.62 K-wire will hold the fracture if a POP doesn't.

Certain intra-articular radius fractures are fracture/dislocations (Fig. 20.4). Postreduction and follow-up x-rays need to confirm capitellar-lunate alignment with the long axis of the radius. If the fracture fragments or the wrist alignment can't be reduced and held with a percutaneous pin, an open reduction and pinning is needed.

Instability or dislocation of the distal radial ulnar joint often accompanies distal radius fractures. Most often, the distal ulnar subluxation or dislocation is dorsal and can be reduced by forearm supination. Examination under anesthesia to confirm rotational stability may be necessary.

A treatment that maintains radial length reproduces the normal 12–15° volar tilt and 23° radial inclination and reconstitutes articular congruity giving the best possibility for satisfactory post-injury function [2].

In many developing countries, the majority of distal radius fractures are handled by local healers, and they often present to the OPD or clinic with striking deformities and x-ray irregularities. A careful history and exam focusing on the patient's specific complaints will help determine the course of action. Younger patients and those needing full function may benefit from surgical correction or reconstruction (see Chap. 41). However, patients with limited demands may only need reassurance and mobilization exercises (Fig. 20.5).

Fig. 20.4 (**a**, **b**) X-rays of an unstable volar Barton's fracture dislocation

Scaphoid Fracture

If presenting early and with minimum displacement, these fractures can be treated in a thumb spica cast, above or below the elbow, as the surgeon chooses. Due to minimal swelling, lack of deformity, and early resolution of initial pain, many patients consider the injury a sprain and only present after the fracture has progressed to a painful nonunion. Open treatment by the volar or dorsal approach to correct the deformity or shortening and held with two parallel K-wires, with local or iliac bone graft, usually gives satisfactory healing of the fracture but may not resolve the pain associated with intracarpal incongruity and instability or arthritic changes in adjacent joints [3].

Metacarpal Fractures

Metacarpal fractures can usually be treated with closed reduction and splinting. Rotational correction can be maintained by selectively buddy taping the fingers, making sure the finger nails align and the flexed finger tips point to the scaphoid. Unstable MC fractures can often be successfully stabilized if both dorsal and volar slabs are applied as two separate splints to control the deforming forces.

If external splinting doesn't hold the reduction, percutaneous pinning with a longitudinal K-wire acting as an internal splint should hold the reduction. Buddy taping the adjacent fingers may be necessary if the K-wire does not control

Fig. 20.5 (**a**, **b**) X-rays of a right distal radius fracture healed with the distal fragment shortened, dorsiflexed, radially displaced, distal R-U separation, and scapholunate disruption. (**c**, **d**) Prominent ulnar head and widening of the wrist are present, but the patient has no limitation in supination and pronation and no pain

rotation. Alternatively, K-wires placed proximal and distal to the fracture and drilled into the adjacent, non-fractured metacarpal will hold the fracture aligned and to length while it heals. Make sure the fracture isn't distracted [4].

Fractures of the Phalanges

Fractures of the phalanges, though often open and involving the joints, are usually treated with splinting. Aluminum-foam or specialized plastic splints are rarely available. For treatment of a fracture involving one finger, e.g., a mallet finger, middle phalanx, or distal phalanx fracture, wrap a dry plaster bandage around the finger, submerge it in water, and mold the POP into the desired position. A small "nubbin" of the plaster end left on the dorsum of the POP acts as a focus for unraveling the cast in warm water when it is no longer needed.

For more unstable fractures or those involving multiple fingers, the broken finger(s) can be buddy taped and immobilized in volar, dorsal, or both volar and dorsal splints extending from the fingertip proximally to the forearm. The goal is to allow the fractures to heal in a functional position. Often these injuries present late and, if intra-articular, are best served with a fusion.

Open phalangeal fractures can be treated with an external fixator made of K-wires drilled through a plastic syringe needle cap to maintain position until the soft tissues heal (Fig. 20.6).

Other Injuries and Conditions of the Wrist and Hand

Lunate Dislocations, Perilunate Dislocations, and Transscaphoid Perilunate Fracture/Dislocations

Lunate dislocations, perilunate dislocations, and transscaphoid perilunate fracture/dislocations are not common. Patients usually present fairly early, and the correct diagnosis depends on the quality of the x-rays and the ability to identify each carpal bone and its relationship with the rest of the carpus and the distal radius on true PA and lateral x-rays. Oblique films and fluoroscopy can be helpful. Sometimes these injuries can be reduced closed with relaxing anesthesia using either manual manipulation or hanging in finger traps. Using a C-arm, they can be pinned closed. Otherwise, they need to be opened, reduced, and pinned volarly—through an extended carpal tunnel incision—or dorsally, usually between the third and fourth dorsal compartments. The exposure depends on which side the major pathology appears to be located. Sometimes both approaches are needed for reduction in complex- or late-presenting cases. If the carpus is opened, carefully repair the capsule and ligaments. Twelve weeks immobilization is recommended (Fig. 20.7).

Fig. 20.6 External fixation of open fractures of middle and ring finger proximal phalanges using K-wires drilled through a plastic needle caps that provide external stability and alignment

Bennett Fracture Dislocations

Bennett fracture dislocations can usually be reduced and held in a short-arm thumb spica POP that extends distal to the thumb IP joint. Radially applied pressure on the base of the first metacarpal with ulnar counter pressure on the neck of first metacarpal (not the proximal phalanx) should reduce the fracture dislocation. If maintenance of the position isn't possible in a cast, a K-wire from the proximal first MC to the second MC or to the trapezium will hold the reduction. A true AP x-ray of the thumb basilar joint to check the reduction can be obtained if the patient maximally pronates his hand to place the dorsum of the first metacarpal against the x-ray plate.

Complex Dislocations of the MP Joints

Complex dislocations of the MP joints by definition require an open reduction. Most often, the index, little finger, or thumb is involved. Dislocations presenting early can be reduced through a volar, dorsal, or lateral incision. They are usually stable with the flexed MPs splinted in a dorsal slab that allows active volar flexion of MP and IP joints but restricts MP extension (Fig. 20.8).

Late-presenting cases may require both dorsal and volar open approaches and occasionally release of a portion of the collateral ligament in order to reduce the joint. These may be unstable, requiring K-wire pinning in MP flexion. Vigorous postoperative IP motion is encouraged, but often the fingers remain permanently stiff from the scarred and shortened soft tissues. If the patient is relatively pain free and is able to do most things with his hand, it may be best to leave the dislocation unreduced (see Fig. 18.3).

Boxer's Fracture

Boxer's fracture of the fifth or fourth metacarpal neck is common and often presents late. Angulation up to 45° of flexion is usually well tolerated. But if the flexed and/or rotated deformity leads to a painful grip, especially in manual laborers, closed or open reduction held with K-wires will improve the alignment.

Clenched Fist Injury

A clenched fist injury from a human tooth, with or without a fracture, requires surgical exploration, debridement, and inpatient IV antibiotics.

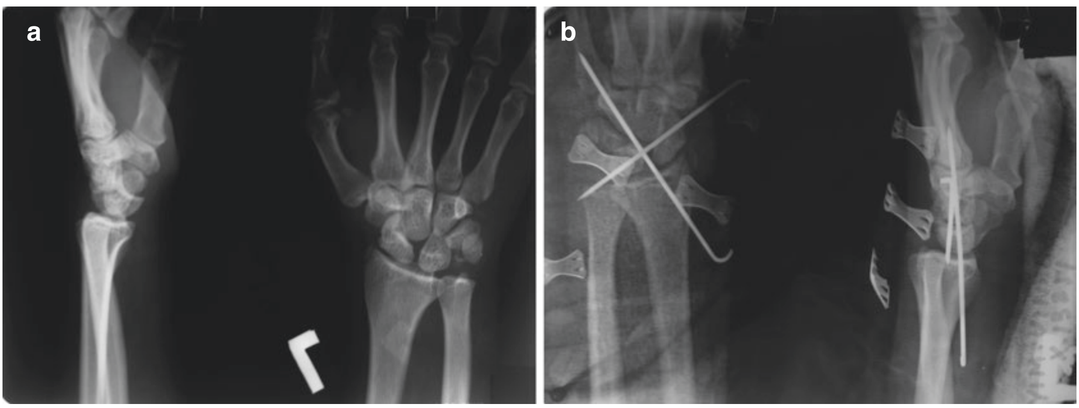

Fig. 20.7 Perilunate dislocation (**a**) x-ray presentation (**b**) after closed reduction and crossed pinning. Scapholunate dissociation persists, but carpal alignment is restored

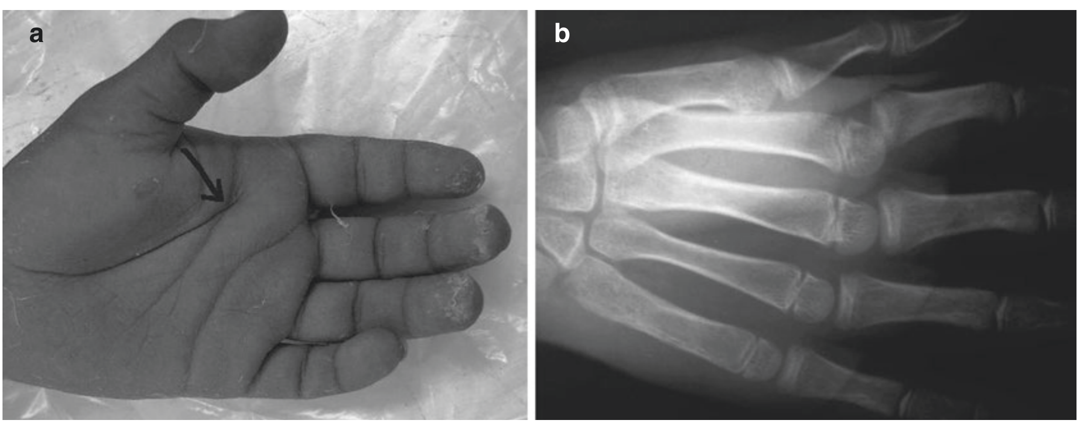

Fig. 20.8 Complex index MC dislocation. (**a**) *Arrow* points to characteristic palmar pucker. (**b**) X-ray showing index MCP incongruity

Penicillin will cover *Eikenella corrodens*, with additional coverage for staphylococcal, streptococcal, and anaerobic bacteria.

Carpal Tunnel Syndrome

Median nerve compression at the wrist gives numbness, paresthesias, or pain in the typical distribution of volar thumb, index, middle, and radial half of ring fingers, but symptoms can extend proximally in the arm. Weakness with atrophy of thenar muscles is a late occurrence. Symptoms are usually worse at night, and there is a high association with diabetes, thyroid disease, and pregnancy (exam for CTS: https://www.youtube.com/watch?v=Ze9piW3wgYw).

Night splinting with the wrist in 15–20° extension, NSIDs, or cortisone injections can relieve symptoms, and if not successful, surgical release of the flexor retinaculum can be performed (https://www.csurgeries.com/video/open-carpal-tunnel-release/).

Stenosing Tenosynovitis (Trigger Finger)

Finger stiffness or locking in a flexed position is caused by enlargement, swelling, or bumps on the flexor tendon along with constriction of the pulley, usually the A1. Cortisone injection in the flexor tendon sheath is often effective in limiting the condition (https://www.youtube.com/watch?v=0VSxtk1oQ2s). If not the A1 pulley can be released (https://www.youtube.com/watch?v=JtqGbwJAAVU).

High-Pressure Injection Injuries

High-pressure injection injuries usually present as puncture wounds in a digit or palm, along with swelling, pain, and redness. The patient and his family must be counseled about the seriousness of the injury as they often appear benign to the casual observer, but the injected material is often irritating or toxic and can extend proximally in the arm and cause a compartment syndrome. These injuries require urgent decompression and debridement, supplemented with antibiotics, splinting, and elevation. Wounds should be left open and the patient returned to the operating room in 24–48 h for further debridement as needed until the skin is closed or grafted. Intraoperative pictures are helpful, as these injuries can lead to amputation (Fig. 20.9).

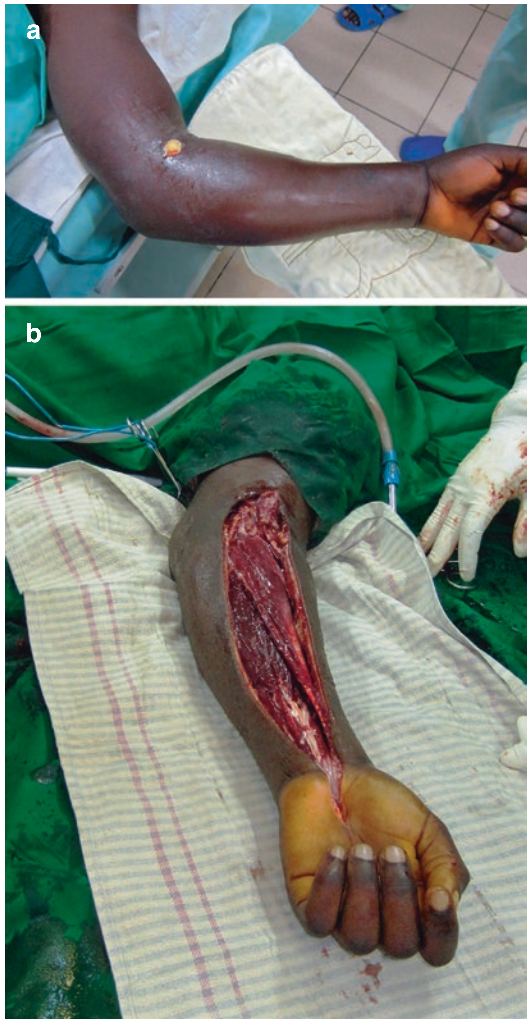

Fig. 20.9 Though not a true high-pressure injection injury, this patient injected insecticide into his antecubital area, which caused a painful chemical reaction. (**a**) Pre-op appearance of left arm. (**b**) The insecticide had liquefied and necrosed the fascia, leaving most of the muscle intact but, as the picture shows, abnormally colored

Pyogenic Flexor Tenosynovitis

Pyogenic flexor tenosynovitis in austere environments most often presents late as a full-blown infection after a minor puncture wound. Kanavel's signs of semi-flexed finger, fusiform swelling, exquisite tenderness along the flexor tendon, and pain on passive extension of the digit are often all present. The flexor tendon sheath is usually full of thick pus and needs an extensive open debridement, generally through a mid-lateral incision with drainage catheters left in place, elevation, splinting, multiple antibiotics, and often repeat visits to the operating room. Even under the best circumstances, good functional results are rare.

Machete Injuries

Machete injuries to the hand and wrist are common in countries where these knives are used as an all-purpose tool. Though the wounds may be contaminated, the cuts are often clean with little soft tissue crush. The circumstances will dictate how and what tissues to approximate. The goal is to leave a functional hand, not a specific complement of digits (Fig. 20.10).

The Mangled Hand

These high-energy injuries involve multiple structures and are usually due to industrial, farm, or motor vehicle trauma. Injuries can be segmental and often have a significant crush or degloving component as well as gross and ground-in contamination, all of which make the initial OPD determination of viable structures inexact. Early tetanus and antibiotic coverage are important as with any open injury (Fig. 20.11).

A thorough evaluation can usually only be done after cleaning in the OR, but the motor and sensory exams must be done before anesthesia is given. Debridement should be thorough yet conservative. Viable skin, even without the underlying bone, can be preserved and used as a fillet flap. Unstable fractures may need to be pinned, but the most important goal of the initial surgery is debridement. External splinting with plaster splints is usually satisfactory after the initial procedure. Tendons and nerves should be tagged for later repair. Intraoperative pictures are helpful for patient and family education and in seeking consultation from colleagues.

The decision-making for such injuries is complex. For a short-term volunteer surgeon who doesn't know if anyone will be able to carry on at his or her departure, or one who is uncomfortable doing hand surgery, these injuries can be anxiety provoking. Reconstructive possibilities are limited. The main goals are to prevent infection, remove all nonviable tissue, preserve useful function, elevate the hand to prevent edema, and splint the hand and wrist in a functional position: wrist dorsiflexion, MP flexion, and IP extension. Consultation with the local doctors, nurses, and therapists will help produce the most useful result within the local restrictions.

Conclusions

Hand and wrist injuries are common and can usually be treated nonoperatively except in specific injury configurations that have been shown to benefit from either open or open and stabilization procedures. The goals are to preserve function and limit pain.

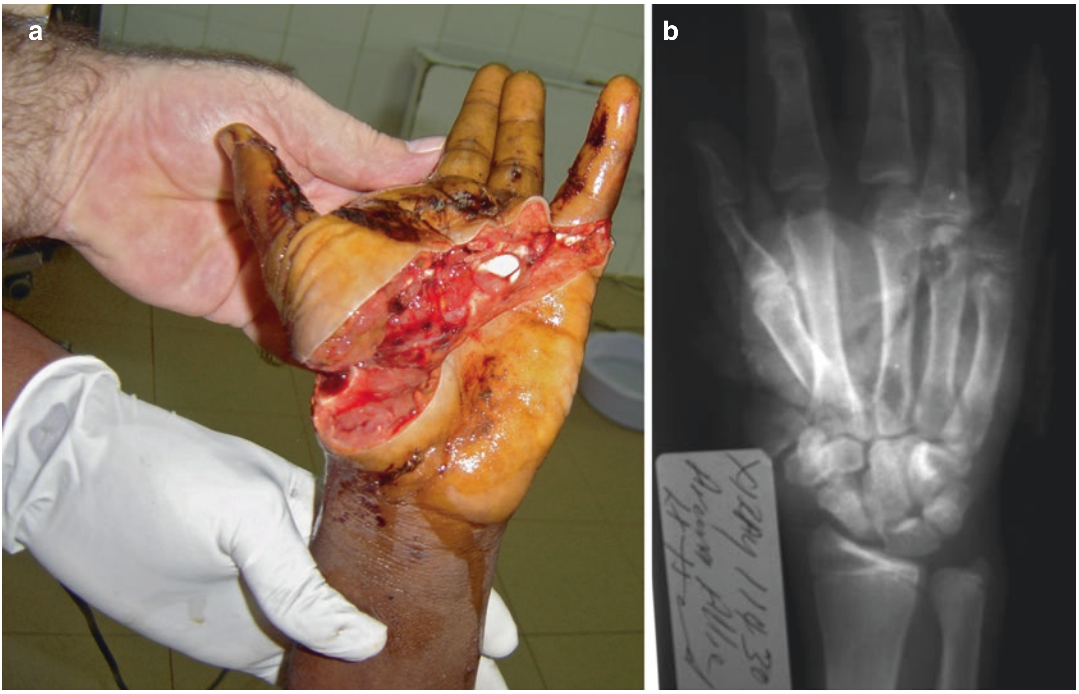

Fig. 20.10 (**a**, **b**) Machete injury to the hand cutting across the base of first MC, palmar soft tissues, including nerves, arteries, tendons, and scoring the distal fourth MC

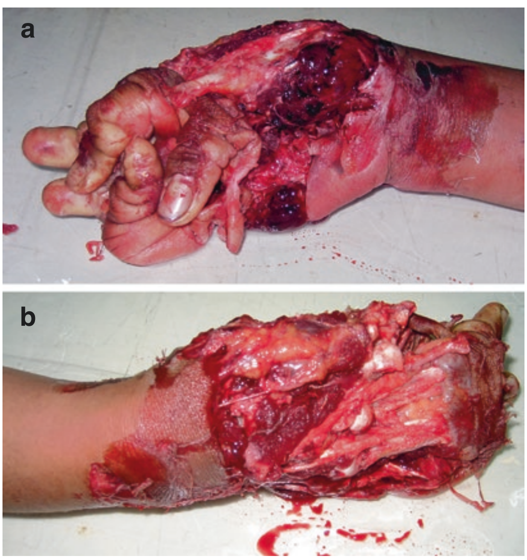

Fig. 20.11 (**a**, **b**) Hand mangled in an agricultural machine with degloving and crush components

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Video of examination of hand https://www.youtube.com/watch?v=uzrdieKVWTc.

21 Trauma of the Pelvis and Acetabulum

Richard A. Gosselin and Anand Sobhraj Devnani

Introduction

Simple pelvic fractures such as avulsion or rami fractures are rarely seen in orthopedic clinics of developing countries. Most heal on their own with symptomatic treatment and little functional sequelae. More complex fractures can heal with shortening or rotational malunions that affect gait and/or limb length, causing changes in hip joint mechanics, chronic pain, and degenerative joint disease. Occasionally, patients present with symptomatic nonunion involving the pubic symphysis or the sacroiliac joint. Non-orthopedic complaints include neurovascular deficits, urogenital and rectal problems, sexual dysfunction, and psychological problems. As most patients present late, some of these non-orthopedic sequelae may be the reasons for consultation.

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Examination

Trauma patients with a suspected pelvic injury should be assessed according to ATLS protocols, paying particular attention to head, chest, and abdominal injuries. A good history from the patient and bystanders is important and could help determine the amount of energy and the position of the patient at the time of impact. Inspection may show suspicious skin lesions such as small open wounds or tire marks on the skin, deformed or asymmetric iliac crests, or swelling and ecchymosis of the genitalia. Palpation, including the sacroiliac area, can reveal crepitation and localized pain. A visible deformity of the lower limb—such as shortening, malrotation, or abduction/adduction of the thigh—is strongly suggestive of an associated fracture of the hip or femur or a hip dislocation.

Anteroposterior and latero-lateral compression maneuvers may help determine stability but are usually quite painful and may displace the fracture or dislodge any protective blood clot [1]. They should be done only once, in the operating room if surgery is planned for something else, and by the person making treatment decisions. The same applies to the cephalocaudal push-pull maneuver, which is best performed under sedation in the x-ray suite or under fluoroscopy. When gentle passive rotation of the hip is painful, a fractured proximal femur or acetabulum should

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be suspected rather than a pelvic fracture. These are often not easy to tell apart clinically.

A patient should be asked to urinate spontaneously, and the urine is examined for gross hematuria. For those who cannot urinate or who are unconscious, it is mandatory to look for blood at the urethral meatus and do a rectal examination, feeling for a “floating prostate” or a perforating spike of bone, *before* inserting a Foley catheter [2] (Fig. 21.1).

If a urethral tear is suspected, a retrograde urethrogram is easy to do with any available contrast medium. If not possible, a suprapubic cystostomy should be placed without an attempt to insert a retrograde catheter, which could complete a partial urethral tear.

A comprehensive neurovascular examination of the extremities is necessary with results recorded in the chart. When a patient is hemodynamically borderline or unstable, the pelvis should be wrapped in a 15–20-cm-wide sling centered over the greater trochanters, using a bed sheet or a large towel, which is then tightened and clamped [3] (Fig. 21.2). Pelvic binders control bleeding by compressing and stabilizing the fracture, rather than by reducing pelvic volume. They can be used in all patterns of fractures. This simple maneuver has proved to be as effective as other more expensive and sometimes more dangerous devices, such as the MAST suit.

Only in a rare case—in which a patient remains hemodynamically unstable in spite of proper resuscitation and the application of a pelvic sling or binder and where the surgeon is skilled with the use of external fixation, a set is available, and anesthesia resources are comfortable with this type of patient—should acute anterior external fixation be contemplated for hemorrhage control [4] (https://www.youtube.com/watch?v=ifouKV1e5mA).

This is best done through incisions large enough to allow the thumb and index finger to feel both the inner and outer tables to facilitate the insertion of two pins in each anterior crest. A two- or three-bar frame is then loaded in firm but not excessive compression, with the midline bar-to-bar connector or spanning middle bar low enough to permit access to the abdomen if needed

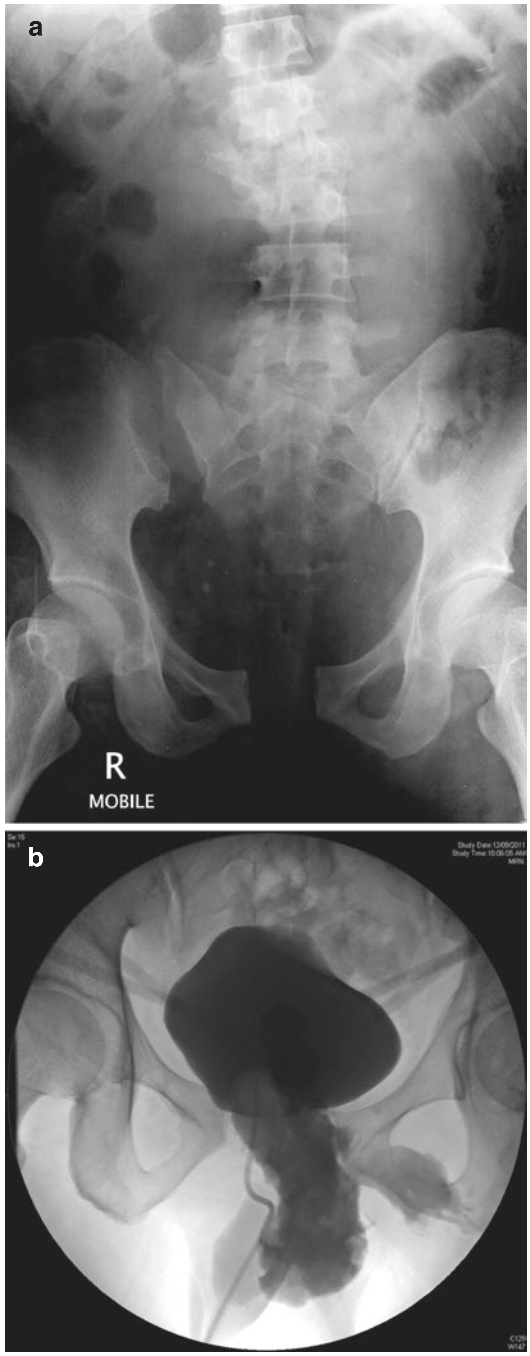

Fig. 21.1 (**a**) X-ray showing disruption of R hemipelvis at symphysis and R SI joint. (**b**) Cystogram showing extravasation of dye through tear in the urethra

for laparotomy and far enough anteriorly so the belly does not rest on it when sitting (Fig. 21.3). Alternatively, two pins can be inserted in the

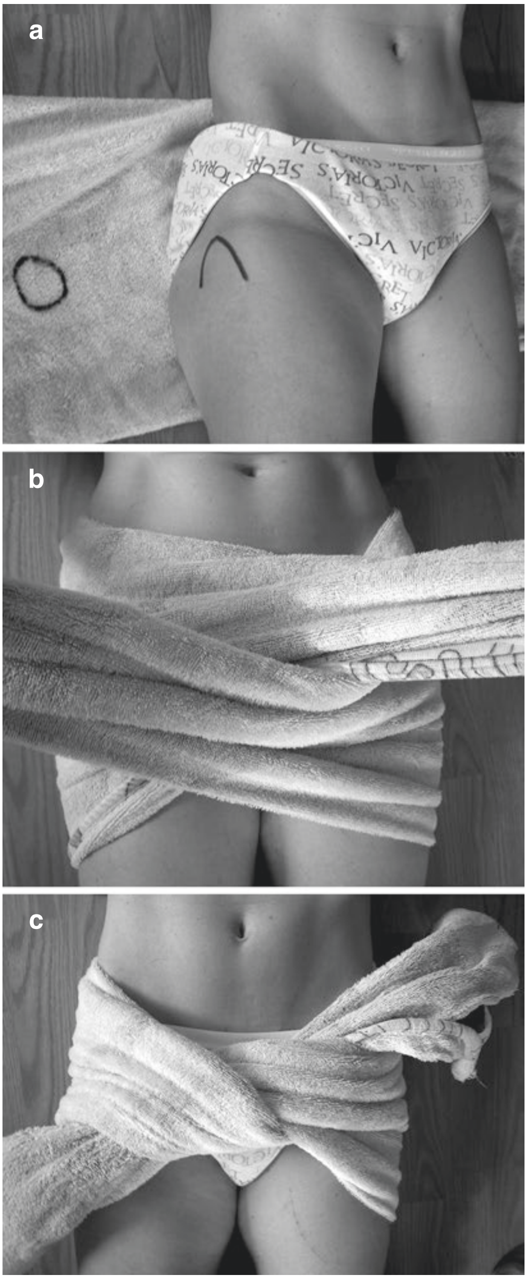

Fig. 21.2 (**a**) Compression wrapping of the pelvis using a towel or a sheet centered over the greater trochanters. (**b**, **c**) Tightening secured with a knot or clamps

supra-acetabular area proximal to the greater trochanter and connected anteriorly with a basic delta frame.

Although a life-saving procedure, the ex-fix often becomes the definitive management of the pelvic ring injury, and reduction should be assessed with appropriate x-rays and, if needed, adjusted once the patient is hemodynamically stable (Fig. 21.4). A patient can usually tolerate 24–48 h of pelvic wrapping, but high blood transfusion demand (often a scarce resource) can mitigate toward external fixation. Arterial embolization is rarely an option, and iliac artery ligature should be considered a heroic maneuver for a patient already undergoing a laparotomy for something else [5].

With the increasing popularity of "damage control surgery," temporary retroperitoneal packing with abdominal pads has shown good results [6]. The patient can be resuscitated and monitored more appropriately and returned to the operating room 24–48 h later for more definitive management of his injuries. Video of pelvic packing (https://www.youtube.com/watch?v=RYHbEPE-Tno).

Diagnostic Investigations

Radiographic investigation is often limited to an AP pelvis x-ray [7]. It is important to compare the damaged hemipelvis with the intact opposite side. Usually, enough of the lower lumbar spine is included to confirm if the AP view is true or the patient was rotated by noting the alignment of the spinous processes and the pedicles.

Start with evaluation of the pubic rami and measure any separation of the symphysis pubis. Widening less than 2.5 cm is managed nonoperatively, while a diastasis of more than 2.5 cm usually means associated sacroiliac involvement, increasing the possibility of instability. Perform a systematic assessment of the symmetry of the inferior sacroiliac joints, iliac wings, obturator foramina, pelvic inlet, and teardrop. Evaluation of the teardrop is especially helpful in excluding an acetabular fracture. Aspherical incongruency of the hip joint needs to be particularly assessed to rule out a fracture and/or dislocation. Radiographic landmarks for the acetabulum include the anterior and posterior wall, the ilio-innominate and ilio-ischial lines, the acetabular dome, and the teardrop (Fig. 21.5).

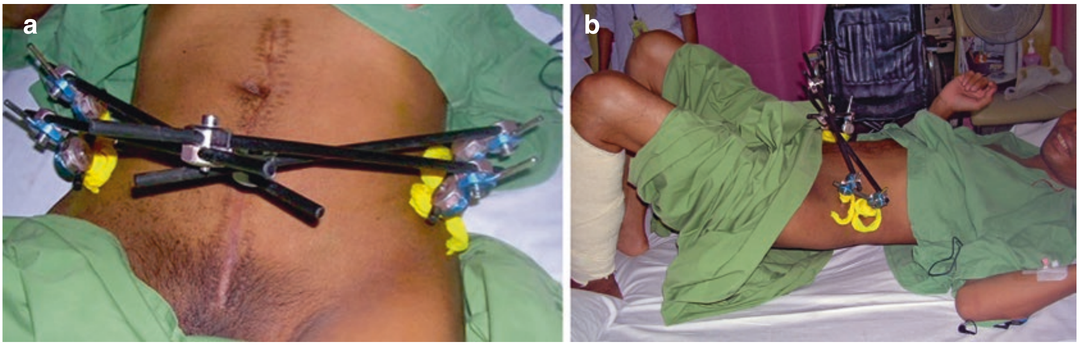

Fig. 21.3 (**a**) Simple external fixator configuration for pelvic ring compression. (**b**) Patient is able to lift himself from bed

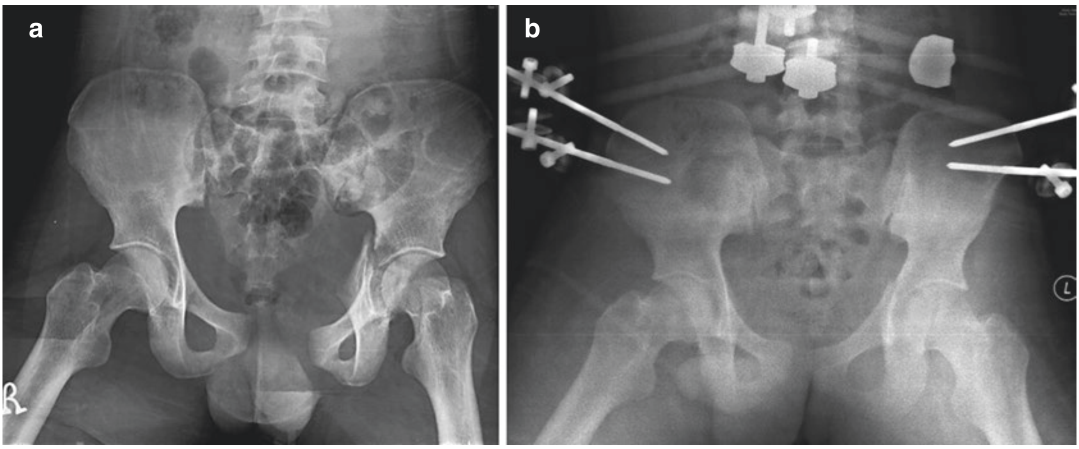

Fig. 21.4 (**a**) AP pelvis x-ray showing significant pubic diastasis, transverse or T-type fracture of the left acetabulum, and probable involvement of the left sacroiliac joint (asymmetric ala and fracture of left fifth transverse process). (**b**) Acceptable reduction of the pelvic ring after application of anterior external fixator in compression. The acetabular fracture is still slightly displaced, but the femoral head is concentrically reduced under the acetabular dome

Indirect x-ray signs of pelvic instability and ligamentous tears include avulsion fractures of the ischial spine, medial border of the ischium, lateral border of the sacrum, and lower lumbar transverse processes [8]. Remember, the x-ray shows the position the pelvis has "sprung back" after injury, not the amount of initial displacement. Inlet (Fig. 21.6) and outlet views (Pennal) (Fig. 21.7) are easy to obtain since there is no need to move the patient, and they are helpful in determining the degree of instability. Iliac oblique and obturator oblique views (Judet) (Fig. 21.8) are only helpful if surgery is contemplated. Otherwise, they are of academic interest only and are painful for the patient, so should not be done routinely. CT scans are helpful if available.

Pelvic Ring Injuries

The proper assessment of the stability of the pelvic ring is the key element to management [9]. Stability can be defined as the ability of the pelvic ring to withstand physiologic forces without abnormal deformation. The bony pelvis has no intrinsic stability, but when pelvic ligaments are intact, the sacrum acts as a reverse keystone in the pelvic arch. The posterior sacroiliac ligaments are by far the most important structures to this end. For the sake of simplicity, all injuries involving the posterior sacroiliac ligamentous complex are considered unstable. All others are stable or partially stable.

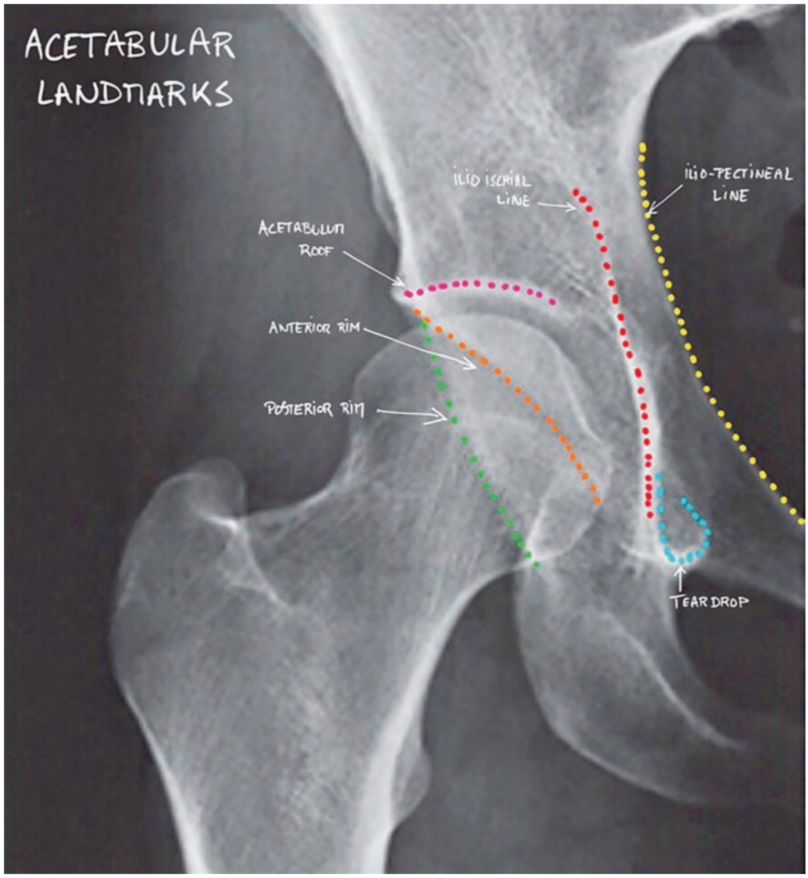

Fig. 21.5 AP x-ray of the right hip showing ilio-pectineal line, ilio-ischial line, teardrop, acetabular roof, anterior wall of the acetabulum and posterior wall of the acetabulum

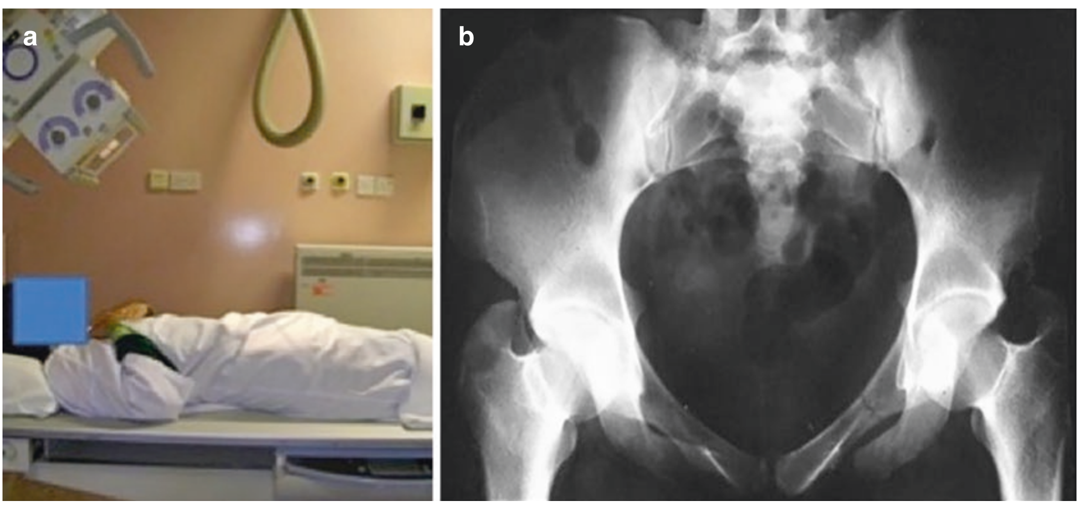

Fig. 21.6 (**a**, **b**) Inlet (cephalocaudal) view is particularly useful to detect rotation in the transverse plane and antero-posterior translation

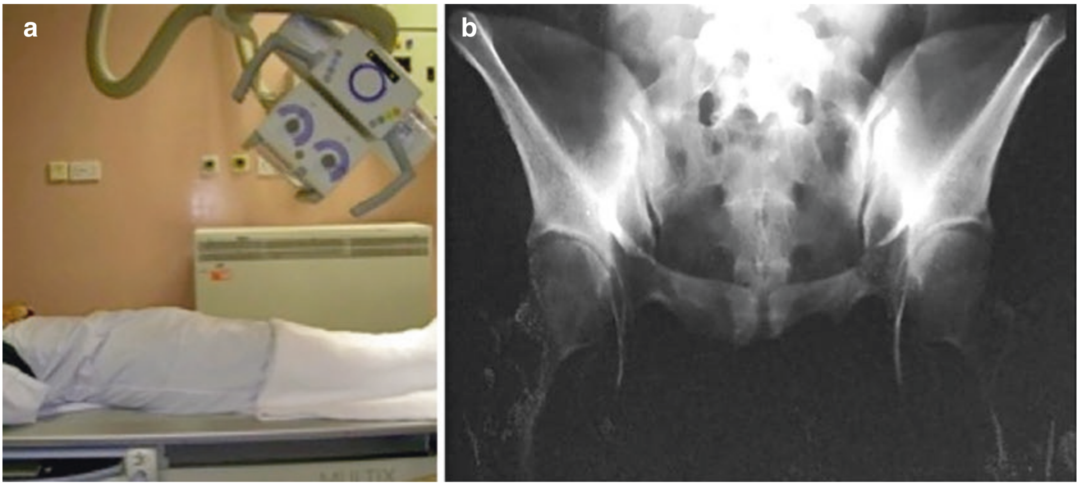

Fig. 21.7 (**a**, **b**) Outlet (caudocephalic) view is particularly helpful for evaluating rotation in the sagittal plane and cephalocaudal translation

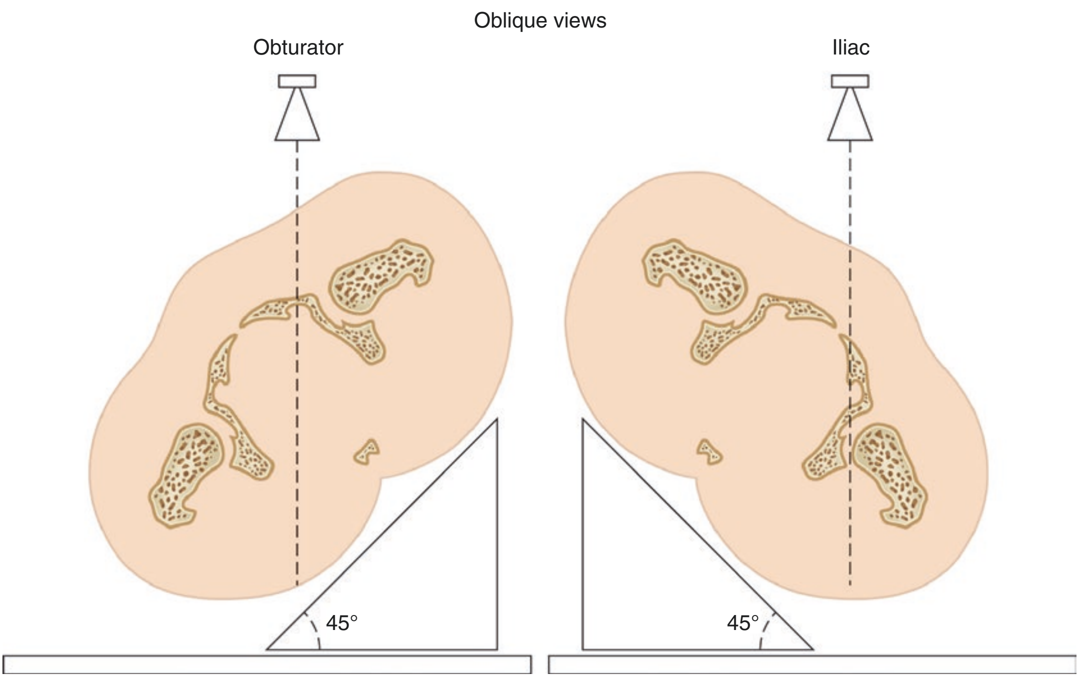

Fig. 21.8 Judet iliac and obturator oblique views

Although the Young-Burgess classification is widely used in the West, its level of sophistication is beyond the practical needs of most resource-poor centers. In these environments, the Bucholz classification is most helpful: *Bucholz type 1* injuries are rotationally and vertically stable, type 2 injuries are rotationally unstable but vertically stable, and type 3 injuries are both rotationally and vertically unstable [10] (Fig. 21.9).

Many stable or partially unstable injuries are overtreated with prolonged bed rest (4–8 weeks) as per conventional wisdom. This commonly leads to associated complications of pressure sores, pin tract infections, thromboembolic dis-

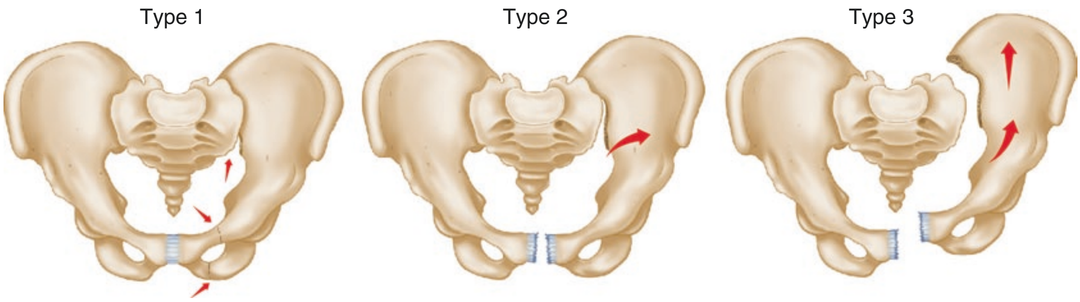

Fig. 21.9 Bucholz classification: type 1, stable fractures; type 2, rotationally unstable but vertically stable (usually open-book or lateral compression); and type 3, both rotationally and vertically unstable (usually shear)

ease, disuse atrophy, and stiffness, particularly where nursing care is lacking. Weight bearing does not affect *Bucholz type 1* injuries: stable avulsions, rami fractures, and low-grade compression fractures. These should be treated symptomatically with minimal bed rest, early mobilization, and ambulation as tolerated.

Bucholz type 2 injuries are commonly of the open-book or bucket-handle type—unstable in rotation but stable in translation. They require longer bed rest but should still be mobilized as soon as pain allows. Reduction of an open-book deformity can be achieved by gravity, with the patient lying on either side. Skin traction for comfort should be sufficient and only necessary for 7–10 days. The patient is encouraged to sit at the side of the bed and progressed to ambulation with a walker or crutches bearing weight as tolerated. Residual pubic diastasis of up to 3 cm is well tolerated in the long run.

When skilled hands and appropriate hardware for internal or external fixation are available, surgery should be considered if there is a residual diastasis of >3 cm or for the polytrauma patient who requires early mobilization [11, 12]. Surgery for patients with Bucholz type 2 injuries is elective, after an attempt at closed reduction with lateral decubitus positioning. Internal fixation is through a Pfannenstiel incision, with an inflated Foley catheter balloon in place to help identify the bladder. The fixation should be rigid enough—usually one DC plate or reconstruction plate with six cortices on each side—to allow immediate mobilization. Meticulous repair of the abdominal wall is necessary to avoid incisional hernias. Video of open reduction and fixation of pelvic ring (https://www.youtube.com/watch?v=GDupbFdxQ-w)

Bucholz type 3 injuries involve the disruption of the posterior sacroiliac bone and ligament complex. These can be purely ligamentous, as in SI joint dislocation; purely bony, as in fractures through the sacral foramina or a Malgaigne-type lesion through the sacral ala or iliac wing; or in combination trans-sacroiliac lesions. A bony and/or ligamentous disruption of the anterior ring accompanies the posterior injury, and there is always a translational component, either a cephalocaudal shear displacement or an anteroposterior displacement. The result is a hemipelvis that is both rotationally and vertically unstable.

X-ray findings are usually obvious but can be subtle, showing only asymmetry of the inferior sacroiliac joints and mild deformity of the anterior ring. Associated fractures of the lower lumbar transverse process, ischial spine, or ischial border should increase the level of suspicion. Inlet and outlet views will show the direction of the most severe displacement. A push-pull maneuver under sedation, with stress x-rays or fluoroscopy, can confirm the diagnosis. In the rare case where it is available, a CT scan can add valuable information but only if it will affect management decisions that can be acted upon.

Bucholz type 3 fractures are completely unstable and require prolonged bed rest if treated nonoperatively. Straight skeletal traction through the distal femur or proximal tibia is indicated, more to prevent further displacement than to reduce that existing and most importantly for comfort. The patient is encouraged to mobilize actively in bed as tolerated. Anticoagulants should be given if available. Progressive sitting is permitted as allowed by pain. When direct palpation of the posterior sacroiliac area, sitting upright, and a gentle push-pull maneuver without traction are all painless, the traction is superfluous and should be removed, usually around 3–4 weeks. Progressive mobilization out of bed is started with crutches or walker, but the patient should remain non-weight bearing for a minimum of 6 weeks, at which time x-rays should show some signs of consolidation. Residual shortening >2 cm can be addressed early with a shoe lift. But many patients will still prefer to go barefoot.

Surgical management is reserved for skilled and experienced surgeons, who are properly equipped and working in an appropriate surgical environment, including access to a blood bank. Both anterior and posterior rings need to be reduced and stabilized if the patient is to be mobilized early; otherwise, the purpose of surgery is defeated (Fig. 21.10). Many of the common approaches and techniques are available on video at the AO foundation webpage (https://aotrauma.aofoundation.org/Structure/education/self-directed-learning/videos/clinical-videos/Pages/clinical-videos-approaches.aspx).

External fixators have a limited role in the definitive management of unstable pelvic fractures, but in combination with skeletal traction, they can be a safe alternative for vertical shear injuries in situations that lack specialized surgical facilities or if the patient's condition is too unstable to undergo more extensive internal fixation [13].

Acetabular Fractures

Complex fractures of the acetabulum (central dislocation of the hip) are usually beyond the scope and ability of most surgeons at home, let alone in an unfamiliar setting with limited resources [14].

The most common fracture of the acetabulum is a posterior wall fracture associated with a posterior hip dislocation (see Chap. 22) and is most commonly visible on the prereduction x-ray. It is important to assess hip stability after reduction,

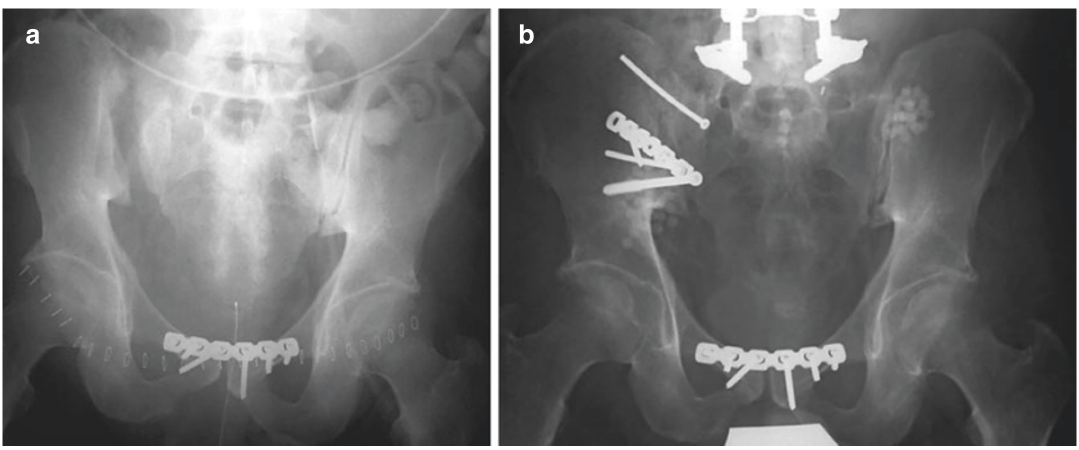

Fig. 21.10 (**a**) First procedure: ORIF with plate and six screws of symphysis pubis, through a Pfannenstiel approach. The right sacroiliac joint is still dislocated. (**b**) Second procedure: ORIF of right sacroiliac joint with multiple screw and a small plate, with near anatomic restoration of the pelvic ring. Note also the presence of the distal end of spinal hardware to internally fix a lumbar spine fracture

while still under anesthesia, and record the results.

An entrapped fragment is a different matter. X-rays may show a nonconcentric reduction or a wider joint space than the opposite side. Always obtain an AP pelvis, not just an AP of the hip. Depending on its size, the piece or pieces need to be removed or fixed, usually through a posterior approach, with the patient in the lateral decubitus position. The joint is explored and the fragments removed. Impaction lesions at the margin of the fracture should be reduced. Posterior wall pieces large enough to be fixed should be reduced and maintained with screws or threaded K-wires if they are the only available implants. Smooth K-wires will eventually migrate and should be avoided or at least bent if used.

Fig. 21.11 Inadequate ORIF of posterior wall fracture, with subsequent re-dislocation of the hip

Simple acetabular fractures involving the anterior wall or column rarely affect hip mechanics. Treatment should be as for partially unstable pelvic ring fractures. All other fractures are complex, and unless near anatomic reduction is achieved, most will ensure premature degenerative changes of the hip. Bad surgery is worse than no surgery (Fig. 21.11). In austere environments, creating a decent bed for a future joint replacement is not a valid surgical indication. Unless *expert* hands are available, acetabular fractures should be managed conservatively with the goal of keeping the femoral head under the acetabular dome (Fig. 21.12). This is best achieved by longitudinal traction in extension. Lateral traction with a "screw-type" device inserted through the greater trochanter or into the femoral head and neck is not helpful, in our experience. It is difficult to insert in the proper position, an effective traction apparatus is difficult to achieve and maintain, and it confines the patient to a prolonged supine position, rarely recreates an anatomic dome-head relationship, and quickly gets "soupy." The disadvantages far outweigh the benefits.

Special mention is made for the "both-column" fracture pattern, where there is no intact acetabulum remaining in continuity with the intact proximal pelvis. Spontaneous "neocongruency" can be seen, in which the displaced acetab-

Fig. 21.12 This T-type acetabular fracture with "central dislocation" occurred when the young motorcyclist's leg was hit head on by another motorcyclist (*left*). The postreduction x-ray (*right*) without traction shows residual incongruity, and though no CT or films in traction are available, the best results will be with 6–8 weeks of skeletal traction, increasing ROM as tolerated to "mold" the joint

ular fragments mold around the femoral head. This usually occurs after 6 weeks of straight skeletal traction. But if traction makes the "neocongruency" worse, as shown by a simple AP pelvis x-ray in traction, it is contraindicated, and the patient should be left at bed rest without traction for 6 weeks at which time a "neo-acetabulum" has formed around the head. Gentle range of motion is started early in bed, whether in traction or not, to promote molding, but the patient should not start weight bearing before 3 months.

Some patients will do well in spite of poor-looking x-rays, others the opposite. Premature DJD of the hip is unfortunately a common outcome (Fig. 21.13). Symptomatic treatment including medication and walking aids are all that most patients will ever receive. Surgical options include arthrodesis (rarely accepted), Girdlestone arthroplasty (rarely accepted), and joint replacement (rarely accessible) (see Chap. 41).

Fig. 21.13 Malunion of a displaced posterior wall fracture, with residual subluxation, and significant narrowing of the medial joint line, with medial osteophyte formation

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Trauma of the Hip and Femoral Shaft

22

Richard A. Gosselin, Faruque Quasem, and Lewis Greer Zirkle

Hip Dislocations

Posterior Hip Dislocations

Hip dislocations are usually high-energy injuries. Posterior dislocations are the most common and often associated with sciatic nerve injury. The classical clinical picture includes pain, shortening, and a flexion/adduction/internal rotation posture of the lower extremity. A plain AP pelvis x-ray should confirm the diagnosis and rule out associated bony injuries. Anesthesia or sedation, preferably with muscle relaxation, is necessary for reduction. Trolleys and OR tables are narrow and unstable, making it safer to place the patient on a mattress on the floor for reduction, while an assistant applies downward pressure on the anterior superior iliac spines. Traction in line with the axis of the femoral displacement—the Allis maneuver—will reduce the dislocation, usually with a clunk after which the leg is extended and externally rotated (https://www.youtube.com/watch?v=sGQZaqB48rw).

A "grinding" sensation on attempted postreduction hip motion suggests an entrapped osteoarticular fragment or missed fracture. If repeated attempts at closed reduction are unsuccessful, interposition or buttonholing is likely, requiring open reduction through a posterior approach.

A postreduction AP x-ray of the pelvis (not just the involved hip) is essential to confirm a concentric and congruent reduction with bilaterally comparable joint spaces (Fig. 22.1). For congruent joints, the degree of instability will dictate further management. A hip clinically stable at 90° can be treated symptomatically, with weight bearing as tolerated and instructions to avoid excessive flexion, adduction, and internal rotation for 2 months. If the hip re-dislocates between 60 and 90°, straight skin traction in external rotation is indicated for at least 2 weeks. External rotation can be maintained by placing the leg in a stockinette tied to the side of bed or a derotation bar incorporated in a slipper cast. The patient should be allowed to lie supine, prone, and on the involved side, but not on the contralateral side to avoid adduction. Traction can be relaxed while the patient is awake but should remain in place at night to prevent re-dislocation. Sitting is allowed as tolerated within the safe zone only. A straight knee cylinder cast, with or without a derotation bar to maintain external rotation of the hip, and

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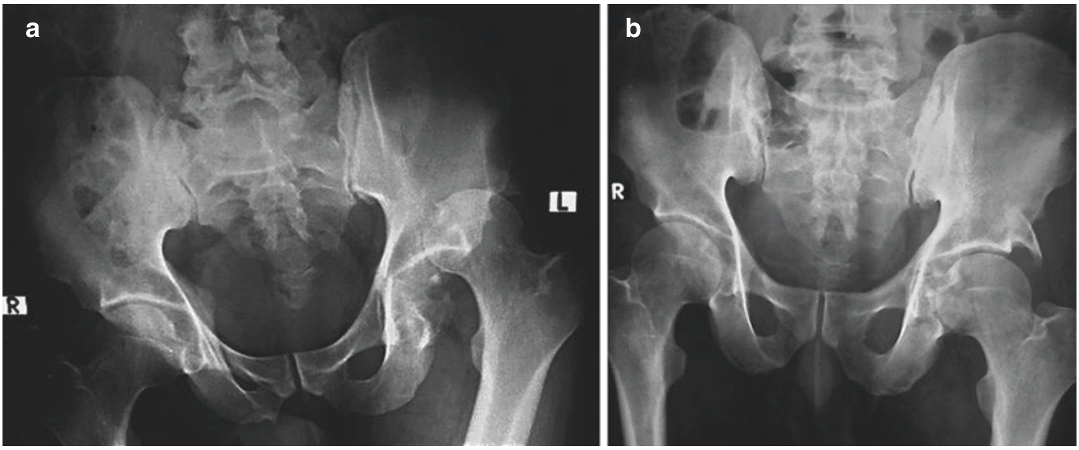

Fig. 22.1 (**a**) AP x-ray of a posterior dislocation of the left hip with fracture of the posterior wall. (**b**) Postreduction x-rays show concentric reduction of femoral head, but the posterior wall fragment remains displaced. Further management depends on clinical stability

augmented by an abduction pillow is another way to limit hip flexion. Inlet/outlet, iliac/obturator oblique views (see Chap. 21), or CT can be helpful in postreduction assessment. Recurrent dislocation of a concentrically reduced hip is rare.

A hip that re-dislocates at 45° flexion or less usually indicates a sizeable fracture of either the posterior wall or femoral head. Large posterior wall fragments should be fixed (see Chap. 21). Large femoral head fragments—from the weight-bearing area, between 10 and 2 o'clock—should be fixed, or otherwise excised, along with the ligamentum teres. Ideal fixation is with two lag screws starting from the femoral neck. For small fragments, a screw head can be countersunk below the articular surface or small threaded K-wires cut flush with the articular surface. The hip is reduced and assessed for stability and the posterior capsule repaired. If stable a non-weight-bearing gait with range of motion starts early and continues for 6–8 weeks. In selected cases, 2–3 weeks of traction may be beneficial. In theory, surgery is indicated for an unstable hip with more than 2–3 mm of residual displacement of the posterior wall or dome fragment. But this is only true if appropriate resources are available; otherwise, the patient is best treated conservatively as outlined above.

The incidence of AVN increases with the duration of the dislocation, but the correlation with time is inconstant [1]. If the dislocation is relatively fresh, the patient usually presents with only mild discomfort at rest, pain on passive motion, shortening, and inability to bear weight. AVN may or may not be present or visible on x-rays at this time.

Potential benefits of regaining length and the ability for painless ambulation by an open reduction must be weighed against risks of creating or exacerbating AVN or neurovascular injury. Open reduction is not indicated if the head is already deformed.

For long-standing dislocations with severe shortening, and no evidence of AVN, it is safer to put the patient in skeletal traction for 2 weeks and evaluate the position of the head on pelvis x-ray. Or, perform a complete hip release, and place the patient in straight leg skeletal traction, with the added risks of a second anesthetic or infection. A successful reduction may still lead to AVN or a painful, stiff hip. Unless arthroplasty is available, fusion and Girdlestone excisional arthroplasty (see Chap. 41) are the only other surgical options. Patients seen after 6 months have adapted to a large extent and should be left alone (Fig. 22.2).

Fig. 22.2 Chronic obturator dislocation with neoacetabulum. The patient walked with an abduction contracture and relative shortening, but no pain

Anterior Hip Dislocations

These are much less common than posterior dislocations (Fig. 22.3). The hip is usually slightly flexed, abducted, and externally rotated, with the femoral head often palpable in the groin. Closed reduction is by traction in the axis of the dislocation, followed by internal rotation and extension. The hip should be examined for stability in extension and if unstable needs treatment in flexion. Joint incongruity or retained fragments are treated as described above for posterior dislocations.

Stable hips can be placed in skin traction for comfort for a few days, avoiding external rotation. Instability in extension is usually due to an associated fracture, with or without fragment entrapment. An open reduction through an anterior approach is indicated, but fixing a fractured anterior wall or column is technically more demanding than the posterior wall, sometimes requiring a separate ilioinguinal approach.

Fractures of the Proximal Femur

The incidence of these fractures in austere environments is increasing as populations age [2]. They are challenging and remain "unsolved fractures" due to lack of fluoroscopy and fracture tables, delayed presentation, poor implants, and few viable alternatives such as prosthetic replacement [3]. Painful nonunions condemn the patient to use walking aids or a wheelchair.

Femoral Neck Fractures

Intracapsular fractures are associated with varying degrees of compromise to the femoral head circulation. Valgus impaction or undisplaced fractures (Garden 1 and 2) have a better prognosis of healing and less incidence of AVN than fractures with varus or total displacement (Garden 3 and 4). Nonoperative management of fractures impacted in valgus can be considered, but all other fresh fractures are candidates for internal fixation, particularly in younger patients.

If fluoroscopy and a fracture table are available, percutaneous compression screw fixation is routine. With fluoroscopy but no fracture table, percutaneous treatment is still possible with a radiolucent table and good assistants by slightly elevating the patient's involved buttock on a cushion so that the femoral neck is roughly parallel to the ground. One scrubbed assistant provides traction on the leg, while an unscrubbed assistant gives countertraction over the contralateral shoulder via a folded sheet passed under the patient, between the legs and over the perineum. The difficulty with this technique is the lack of lateral projection, requiring the surgeon to go by feel along the anterior neck to determine reduction and implant placement.

Regular short-threaded 6.5-mm cancellous screws can be used when cannulated screws are unavailable. Over-drill the lateral cortex with a 4.5-mm drill bit, and advance the blunt tip of a K-wire in a push-pull fashion. This maximizes the tactile information as one crosses the fracture and prevents neck perforation. Positioning and depth can be assessed on a through-table AP view. A second or third K-wire should be inserted parallel to the first, replacing the wires one by one with screws. Even divergent screws will provide some compression. Fluoroscopy will

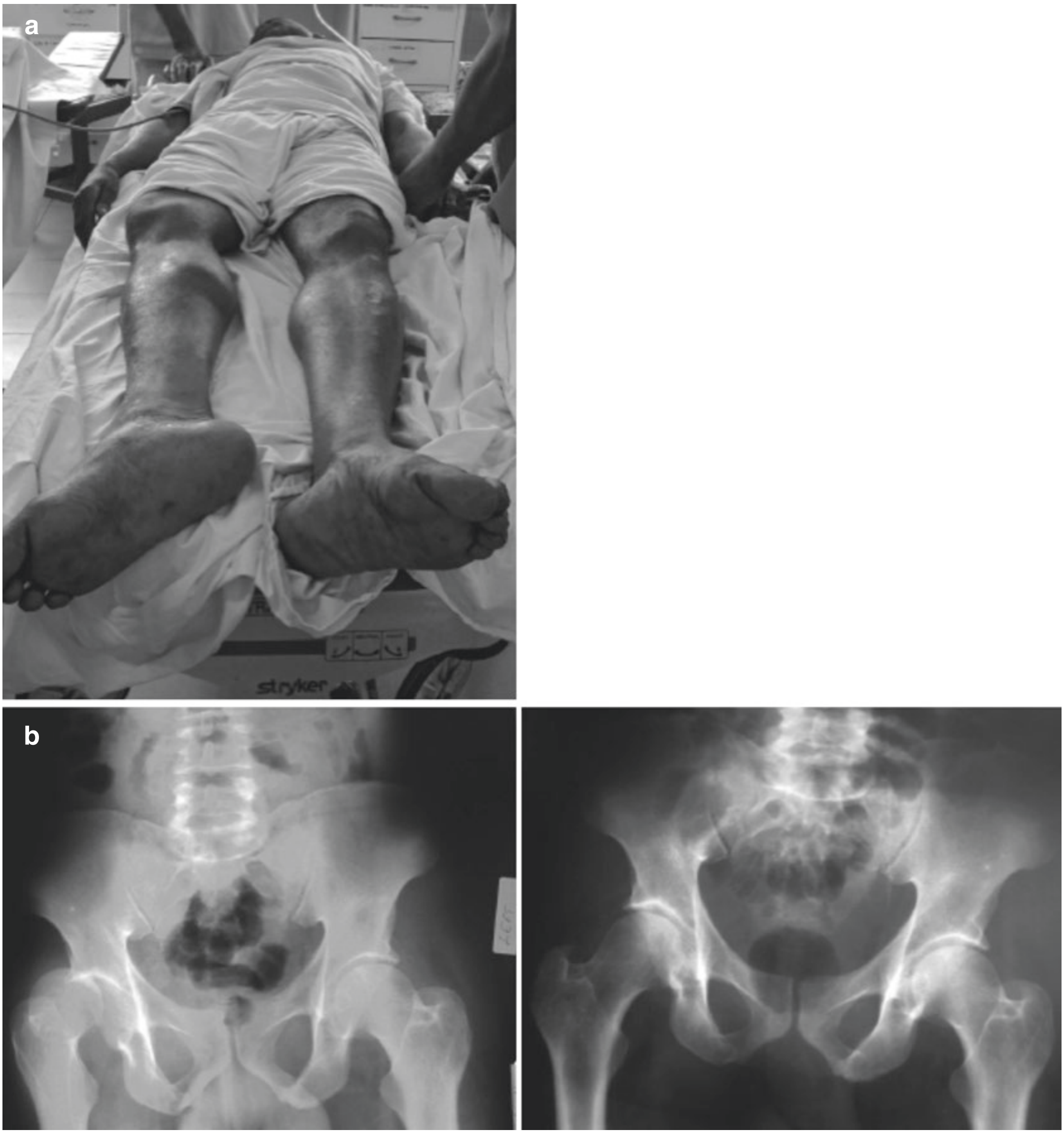

Fig. 22.3 (**a**) The shortened, externally rotated right leg in an anterior dislocation of the hip caused when the farmer slipped and hyperextended his right leg 5 days before. (**b**) Pre- and postreduction x-rays of the pelvis

confirm that the construct moves as a unit, supplemented with a partial frog-leg position or a portable lateral.

When no intraoperative x-rays are available or the fracture is so old that it cannot be reduced closely, the only surgical option is an open reduction through an anterior approach. The anterior neck is rarely comminuted, making the reduction assessable both visually and palpably. A 3.2-mm drill bit can be advanced blindly in the axis of the neck, and parallel to the floor, in a push-pull fashion as described above to a depth as measured on the pre-op x-ray. A second drill bit of equal length is helpful in determining the screw length and is used to drill a second path parallel to the first. The screw is inserted with the first drill bit still in place to prevent the head from spinning. The two screws are compressed, and the construct is tested for stability in movement with no adventitious grinding sensation. A third screw is an option, but the risks of misplacement are higher with this blind technique.

Established painful nonunions without AVN and head deformity may benefit from open reduction, curettage, and compressive fixation, with or without a Judet/Myers procedure (see Chap. 41) [4]. An alternative, especially for neck fractures presenting after 10 days at which point an open reduction may cause more harm than good, is an extra-articular valgus osteotomy at or below the level of the lesser trochanter, to avoid the risk of iatrogenic AVN. Our choice is a 10–20° valgus correction that when fixed with a 135°-degree blade plate, a sliding hip screw, a cephalic nail, or regular short-threaded screws should allow compression at the nonunion and the osteotomy with weight bearing. Temporarily pinning the head to the acetabulum before reaming and tapping avoids spinning the proximal fragment (https://www.youtube.com/watch?v=TAuZTqAAt9g).

When available, hemiarthroplasty is the treatment of choice for nonunion. If degenerative changes in the acetabulum are already present, it should be reamed to subchondral bone and to the size of the selected prosthetic head. When head sizes are limited, reaming to the next size up is a better alternative than using a too small head. Total hip arthroplasty is rarely available and affordable.

Many elderly, low-demand patients with months-old fractures do well with the use of a walking aid, and the western surgeon needs to resist his or her training reflexes and avoid surgery based on x-rays and ingrained habits rather than the patient's needs.

Intertrochanteric (Pertrochanteric) Fractures

These fractures are extracapsular and less likely to develop AVN. They are common insufficiency fractures in the elderly, but significant energy is required for a similar fracture in young adult bone. Patients present with pain, shortening, and external rotation of the limb. Nonoperative management with skeletal traction is usually successful in treating this fracture but requires 6–8 weeks of bed rest before patients can be mobilized without significant discomfort and often leads to malunion with shortening, varus, and rotation. Complications related to bed rest may require earlier mobilization at 3–4 weeks, with an increased incidence of malunion or nonunion. It is not easy to find the delicate balance between what is best for the fracture and best for the patient. Patients who present late may benefit from a shoe lift, as most patients accommodate well to the malunion.

Where fluoroscopy, fracture table, and appropriate implants are available, treatment is closed reduction and internal fixation with a sliding hip screw device or a cephalic nail. Cephalic nails are mechanically better for unstable fractures—those with posterior-medial comminution. Nails with larger proximal diameters risk added comminution at the entry site, making trochanteric entries preferred to piriformis fossa entry.

The proximal locking screws of an antegrade SIGN nail can engage the head and neck fragment of more stable intertrochanteric fractures with the added stability of directed screws running up into the head and neck (Fig. 22.4). SIGN's hip fracture implant and instruments increase the precision of screw placement and give the construct added robustness (Fig. 22.5). (SIGN Hip Construct SHC System Operative Guide PDF available from SIGN Fracture Care International https://signfracturecare.org/).

When comminution is severe, a stable construct is more important than near-anatomical reduction. The distal fragment can be medialized, and the spike of inferior cervical cortex impacted into the medullary cavity (Dimon-Hughston or pushover technique) (Fig. 22.6). The sliding screw can be inserted under direct vision in the neck and the plate secured to the distal fragment. Once the fixation is completed, the surgeon verifies that the construct moves as a unit, confirmed by portable x-rays if available. This gives a stable construct that allows early weight bearing. The healing rate is high, and shortening is treated with a shoe lift (https://clinicalgate.com/open-reduction-and-internal-fixation-of-the-hip/).

External fixation in distraction between iliac crest and distal femoral fragment is a poor

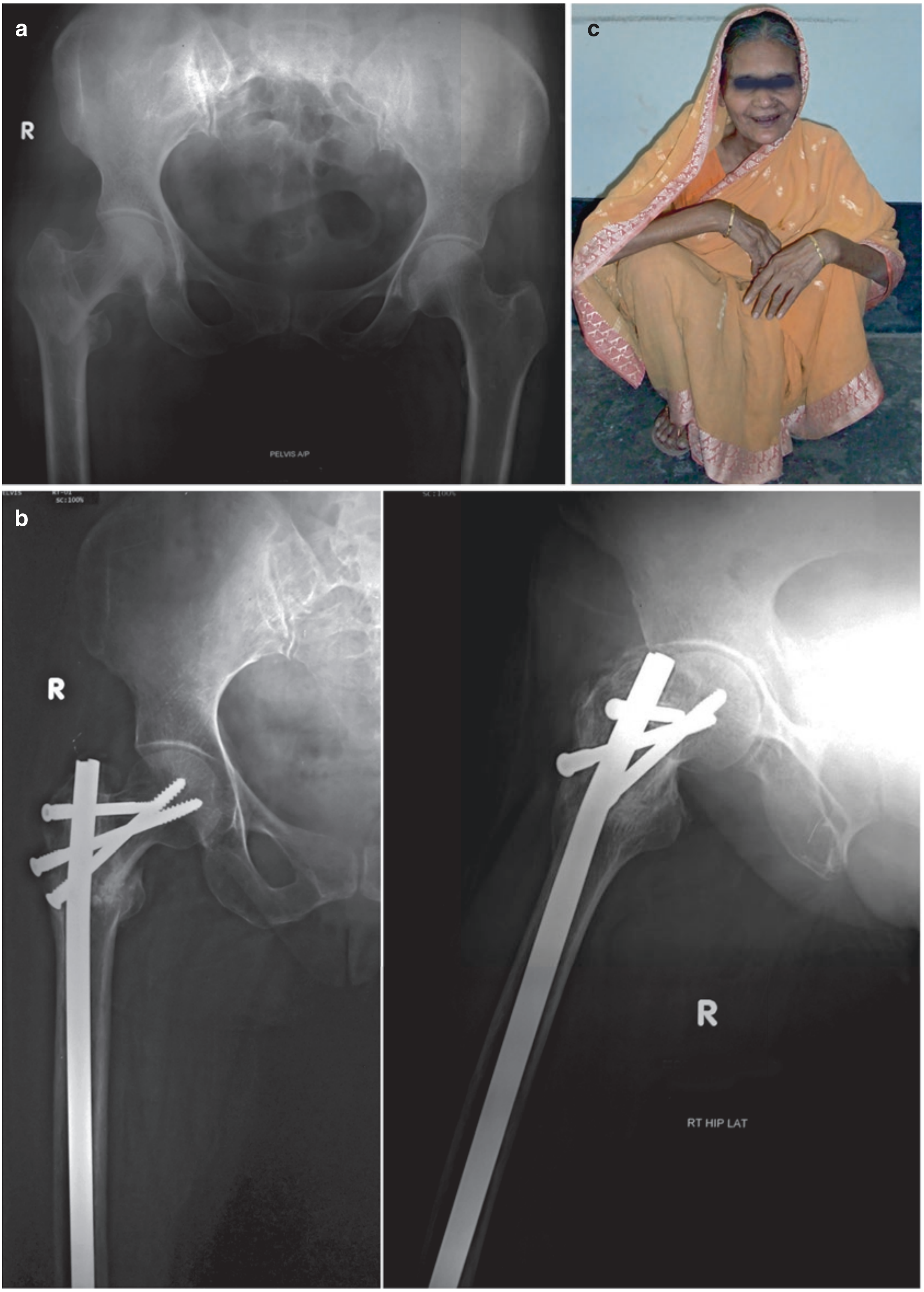

Fig. 22.4 (**a**) X-ray of a two-part intertrochanteric fracture in osteoporotic bone. (**b**) ORIF with the antegrade SIGN nail, with two free screws traversing the fracture and secured into the femoral neck and head. (**c**) The patient after surgery, able to independently walk, squat, and perform ADLs

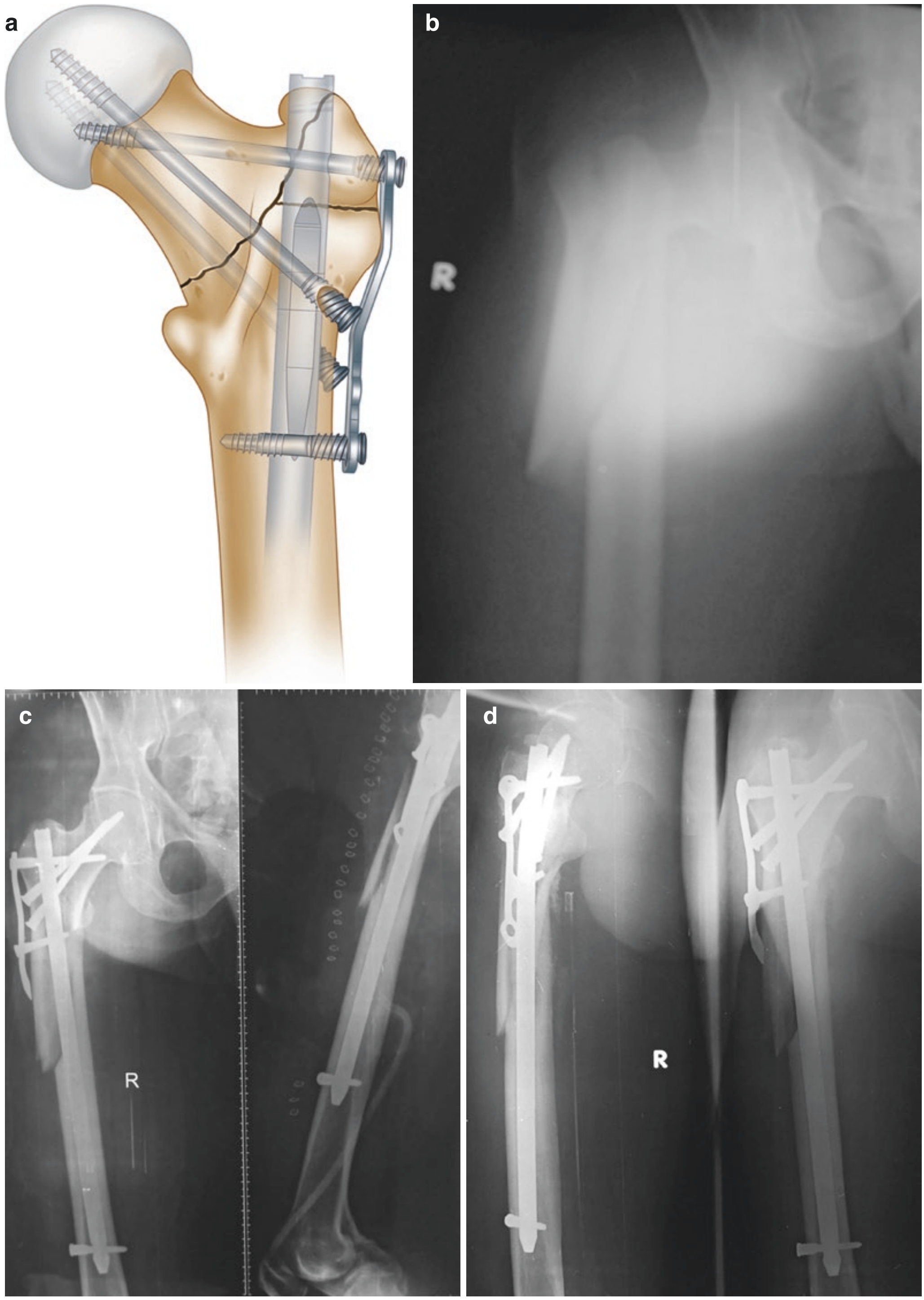

Fig. 22.5 (**a**) Engineer's drawing of the SIGN Hip Construct System. The orientation of the plate and its attachment to both the nail and bone confer stability to the construct, while additional screws are placed into the femoral head and neck by a "miss a nail" technique. (**b**) X-ray of a comminuted inter-subtrochanteric fixation (**c**) Post-op x-ray with SIGN hip construct stabilizing the well-reduced fracture. (**d**) X-ray of healed fracture without loss of position or shortening and patient walking pain-free and without aids

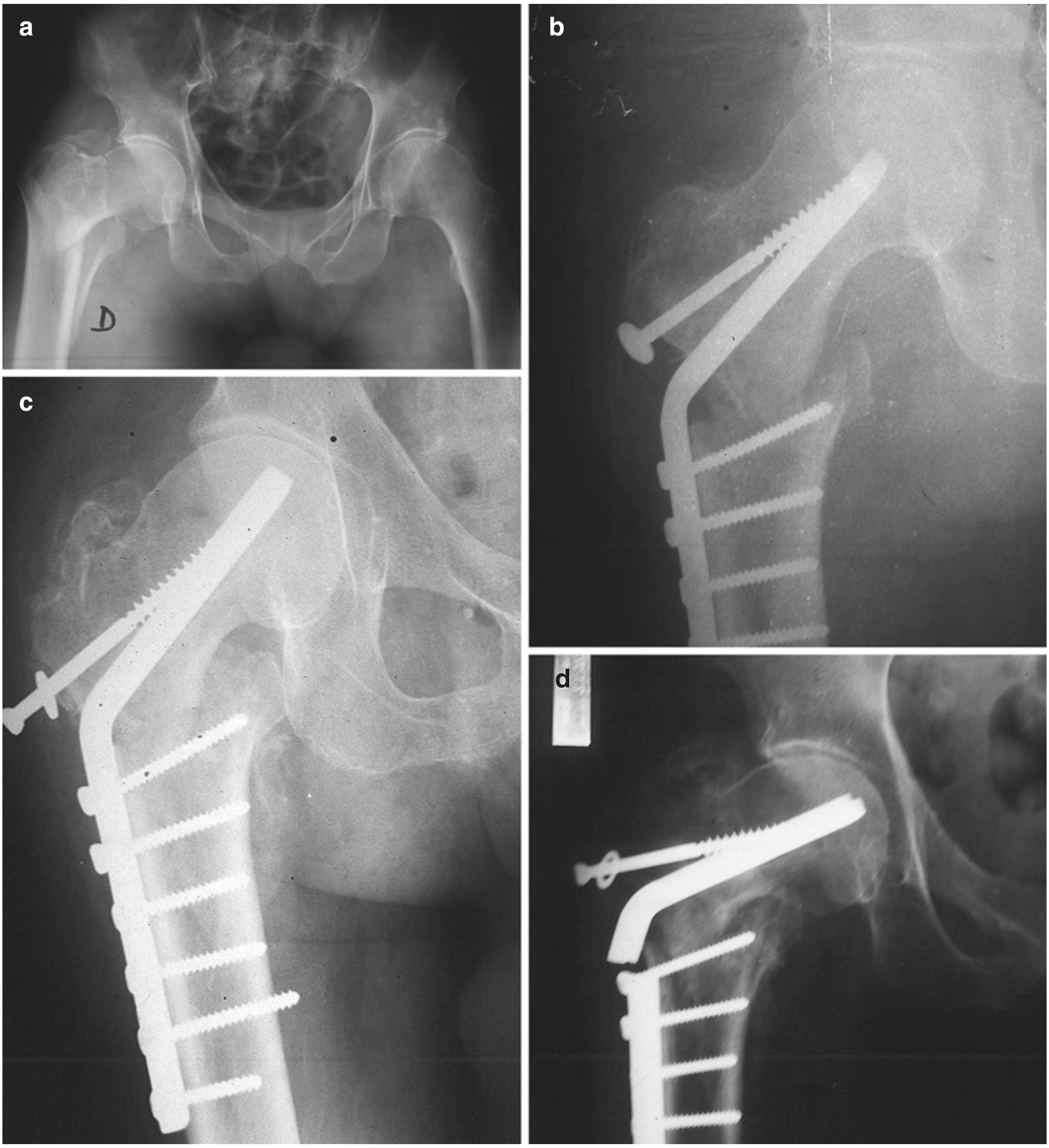

Fig. 22.6 (**a**) X-ray of comminuted intertrochanteric fracture with posteromedial instability. (**b**) ORIF with blade plate and medialization of distal fragment (Dimon-Hughston). (**c**) The blade plate allows for only limited impaction at the fracture site, and the proximal fragment has slid as far as it will go on the rigid blade, defeating the purpose of the impaction. (**d**) The race of bone healing against hardware failure is lost

alternative to internal fixation, only to be considered for wounds on the proximal/lateral thigh.

Painful nonunion of pertrochanteric fractures is not as common as in neck fractures and should be treated with internal fixation, with or without bone grafting, or osteotomy (http://www.ao-danmark.dk/wp-content/uploads/2015/04/Intertrochanteric-Fractures-Ten-Tips-to-Improve-Results.pdf).

Femoral Shaft Fractures

Fractures of the femoral shaft require significant energy. The clinical presentation with shortening and deformity is usually self-evident, though a comprehensive clinical exam to rule out associated injuries is necessary. Isolated femoral shaft fractures rarely cause hypovolemic shock, but many patients in LMICs are borderline anemic before the injury and can quickly decompensate. We cannot overemphasize the importance of seeing the *entire femur on* x-rays, as associated fractures of the femoral neck need to be systematically ruled out. Articular fractures of the distal femur, patella fractures, and/or ligamentous damage should be suspected in the presence of a knee effusion.

Associated Femoral Neck and Shaft Fractures

Whether the femoral shaft fracture is treated surgically or conservatively, the presence of an ipsilateral neck fracture affects the treatment, as well as the functional prognosis. A missed undisplaced neck fracture will displace with skeletal traction or with the manipulation and traction needed for internal fixation. Surgical treatment of both fractures is the best option. The neck should be fixed first, after reduction if necessary, with compression screws that are positioned (usually anteriorly) so as not to impede nailing of the shaft fracture. Temporary Steinmann pins can be used and replaced with screws after shaft nailing. Proximal interlocking screws of the nail can also be used to complement neck fixation, depending on the nail design. Plating is the second best option. If the shaft fracture is too unstable and complicates fixation of the neck, a temporary external fixator can prove useful.

Associated Intertrochanteric and Shaft Fractures

This combination of fractures represents a particularly challenging combination. There is little bone in the proximal femur fragment for secure purchase of an implant. Rigid fixation most often requires long implants such as DHS-type devices, blade plates, long cephalic nails, or IM nails that allow proximal interlocking in the femoral neck and head. If the segment between the two fractures is long enough, each can be treated with separate implants, the hip component as described above and the shaft component with a separate plate or a short retrograde nail.

The SIGN hip system can also be used for this problem in an antegrade fashion with static interlocking. Unless rigid fixation can be achieved, these patients should be treated in traction. The semi-Perkins technique on a Bohler-Braun frame discussed in Chap. 13 is a useful form of traction for such fractures. Nonrigid fixation, such as flexible nailing, should be avoided as it exposes the patient to the same surgical risks without the benefits, as postoperative traction is usually necessary.

Subtrochanteric Fractures

These are usually high-energy injuries, with the proximal fragment displaced in flexion and external rotation from pull of the psoas muscle. When skeletal traction is the only option, it should be done through the distal femur and the limb put in the 90–90° position (90° of flexion at both the hip and knee), with the calf suspended in a sling or lightweight POP boot to prevent equinus and provide elevation. Adults don't tolerate 90–90° traction as well as children. Acceptable compromises include Russell's traction at 45° hip flexion or transtibial pin fraction on a Bohler-Braun frame with a bolster under the thigh to increase hip flexion. Healing requires prolonged bed rest, which poses significant nursing challenges. Whenever possible, ORIF should be performed, ideally with an interlocked IM nail. Plating is mechanically weaker, and medial comminution ensures a high nonunion rate and hardware failure. Using implants with cervical purchase can be difficult without fluoroscopy (Fig. 22.7). Autogenous iliac crest bone grafting may be indicated with severe medial comminution, adding little to the acute morbidity.

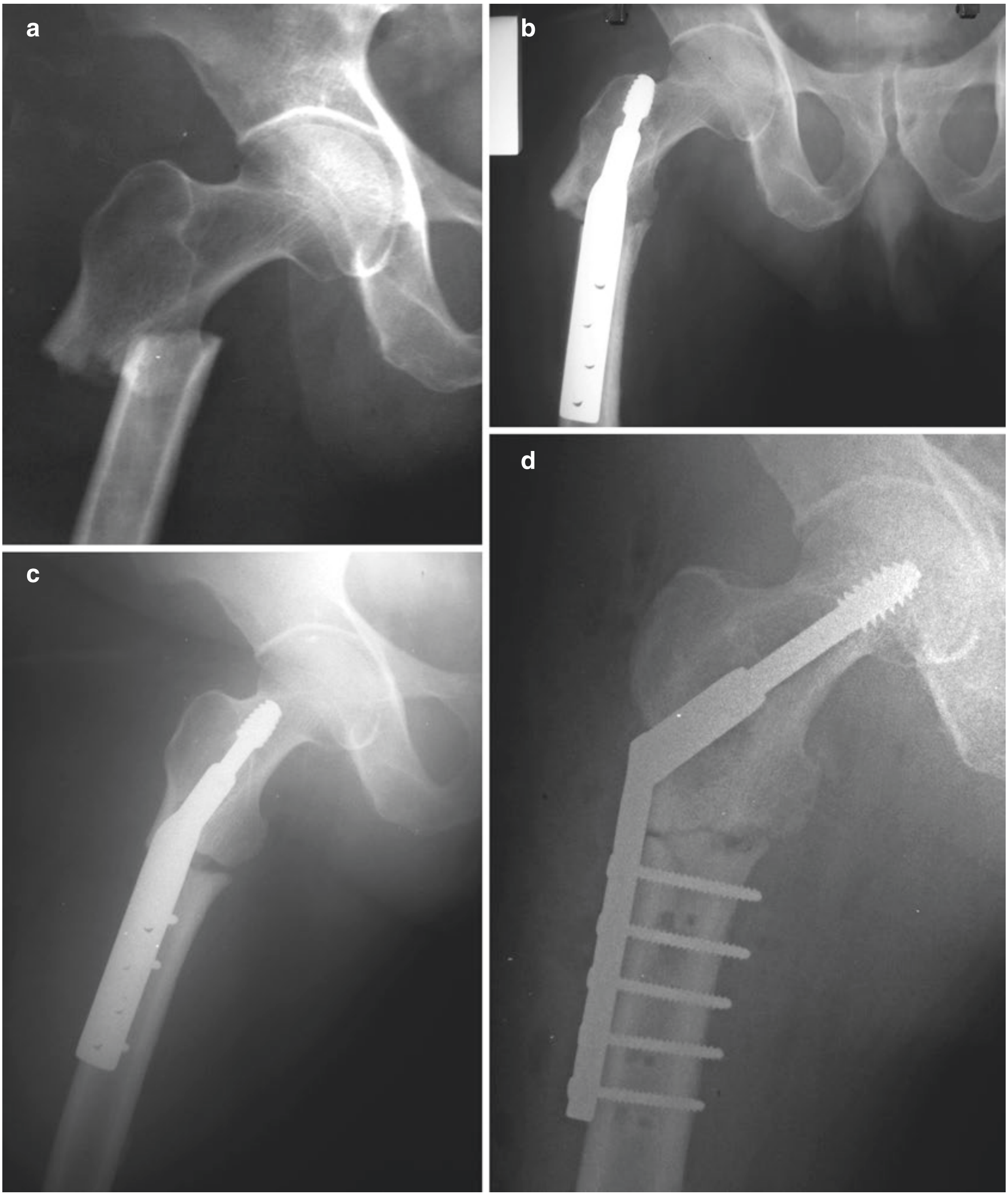

Fig. 22.7 (**a**) X-ray of transverse high subtrochanteric fracture and (**b**, **c**) attempt at blind use of DHS. The compression screw is likely located on or in the superior neck. (**d**) Salvage required an open reduction and direct visualization of the anterior neck. Note the anteroposterior direction of the previous screw holes

Femoral Shaft Fractures

Skeletal traction remains the only treatment option in many austere environments. Unless there are significant wounds, external fixation is a poor substitute for sound internal fixation. Acceptable alignment is difficult to obtain and maintain, pins loosen or become infected, and knee stiffness is common, often with functional disability long after the bone has healed. In most cases, these negatives override the main benefit of early mobilization that external fixation potentially provides. If an ex-fix is used, insert the pins with the knee in flexion, to minimize tethering the vastus lateralis, and once the fixation is secure, the knee should be maximally flexed while under anesthesia.

Any fracture for which skeletal traction is applied as a temporalizing treatment should always be applied as if it is the definitive treatment, as it is common that surgery is delayed indefinitely and traction becomes the definitive treatment by default (for a discussion on femoral shaft fractures treated in traction, refer to Chap. 13).

Whenever possible, internal fixation is the treatment of choice for femoral shaft fractures. Many fractures present late, making a closed reduction impossible. Open reduction of a femur fracture, particularly if old, bleeds copiously, and blood should be available. Many of these patients have underlying chronic anemia before the fresh blood loss from the fracture, and careful monitoring of hemoglobin is mandatory. Prophylactic antibiotic coverage should be routine, according to available wide-spectrum antibiotics.

Intramedullary devices are the implant of choice for most diaphyseal fractures (Fig. 22.8). Traditional open nailing with a Kuntscher nail or other non-interlocked nails relies on 3-point fixation to prevent shortening and rotation. This can be achieved in very few fracture patterns. The same applies to flexible nailing with multiple Ender nails or Rush rods (Fig. 22.9). Nonrigid fixation serves mainly as “alignment” fixation, and postoperative traction or plaster casting may still be necessary, obviating some of the benefits of surgery. In such situations, a well-molded cylinder POP may be needed to hold the proper rotation. In general, unless the patient can benefit from rigid fixation and early mobilization, nonoperative treatment is safer. However, if one is certain from the time elapsed, the position of the fracture ends on x-ray, and the clinical exam that the fracture is incapable of healing without surgical intervention, the surgeon needs to weigh the options.

Interlocking or stacked K-nails with multiple interference screws proximally and distally have been described, but the technique is unreliable and should only be attempted when this is all that

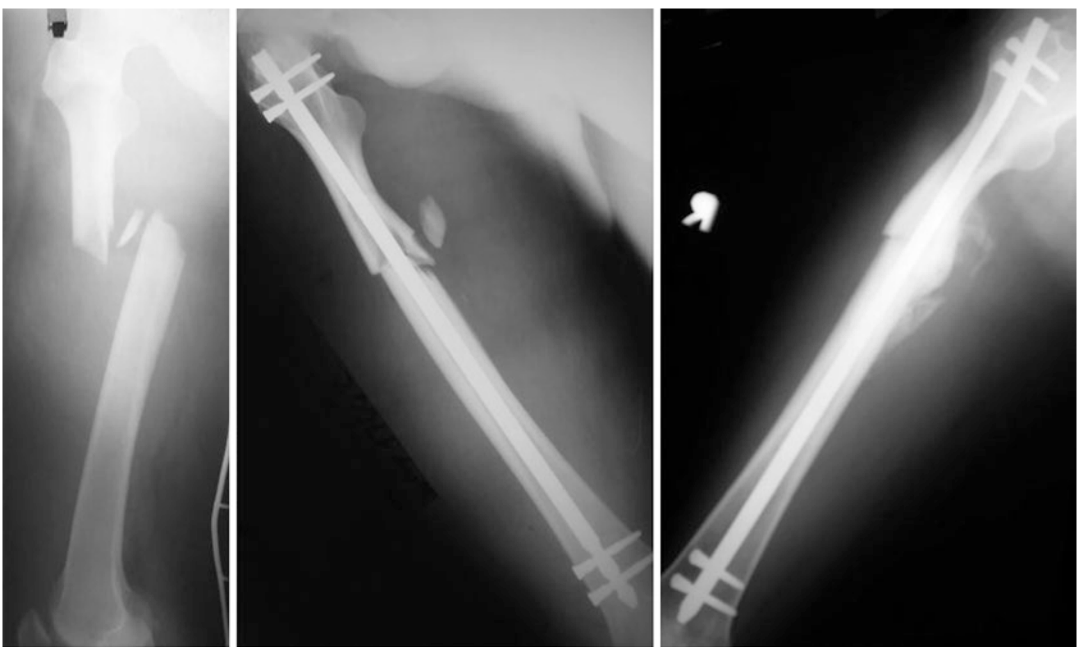

Fig. 22.8 Closed moderately comminuted femur fracture (*left*), fixed with SIGN nail (*middle*), and allowed full early weight bearing as tolerated (*right*). Patient is fully independent without limp at 5 months

is available and nonoperative methods have failed. It is possible to use a generic interlocking nail without fluoroscopy (technique in Appendix 6). The interlocking screws may have little purchase on both the far and near cortices, but the construct is usually strong enough to maintain rotational alignment and length, though not full weight bearing.

The SIGN system (Signfracturecare.org) was developed to allow locked IM nailing without power, fracture table, or fluoroscopy [5]. The system uses a solid nail with a 9° proximal bend with options for four locking screws—two above and two below the fracture. The same nail and targeting system are used for femur, tibia, and humerus shaft fractures, keeping inventory to a minimum. Interlocking is achieved with a rigid external target arm and a system of sleeves to guide precise drilling for the locking screws and slot finders to confirm correct drilling position. The reduction is usually open and reaming is done by hand, using hand reamers, which are part of the system.

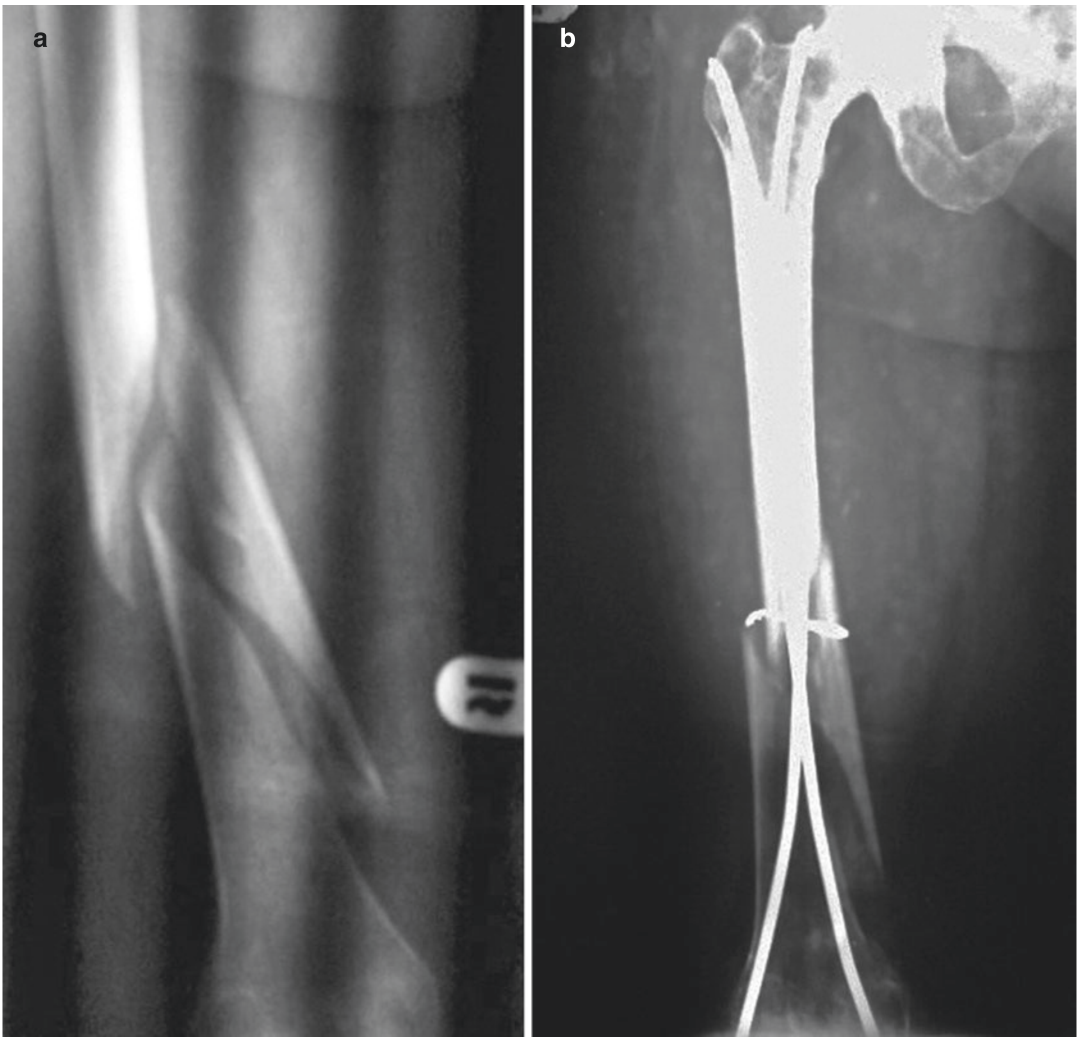

Fig. 22.9 (**a**) X-ray of a comminuted, unstable fracture of the distal femoral shaft. (**b**) ORIF with cerclage wire and two Ender nails and a construct without intrinsic rigidity and stability. Note that one of the rods already protrudes through the femoral neck. (**c**) Predictable malunion with shortening and external rotation. Note migration of the nails distally at their point of insertion. (**d**) Protrusion of the lateral nail through the skin

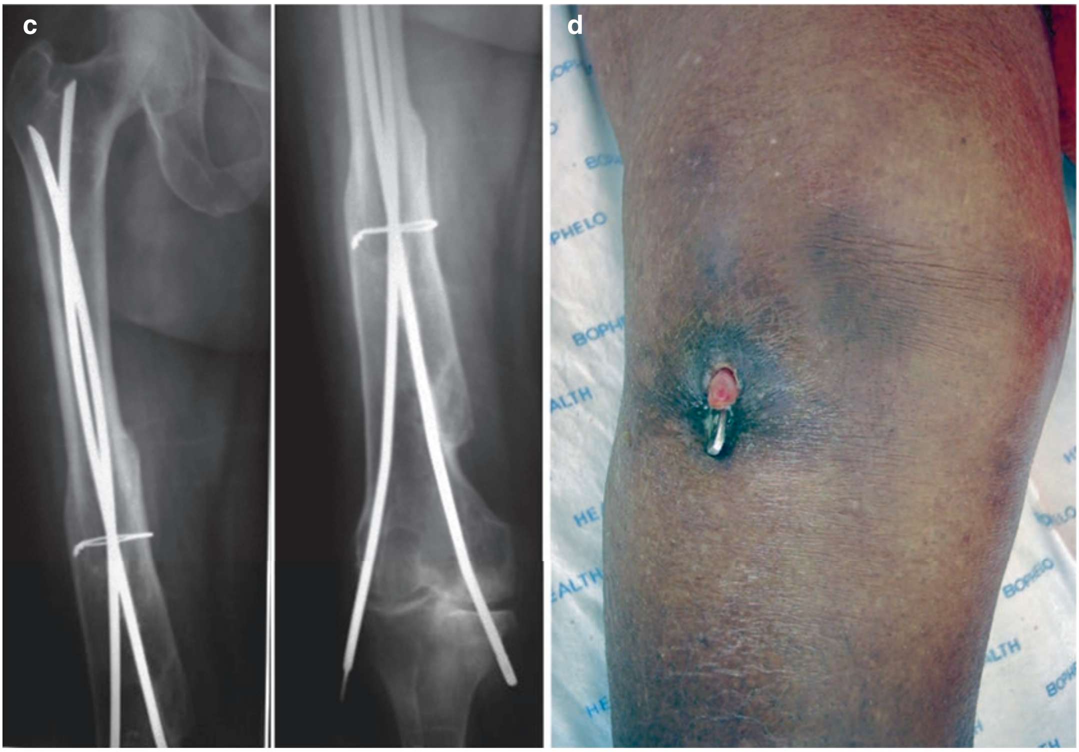

Fig. 22.9 (continued)

The femur can be nailed in an antegrade fashion, using a trochanteric entry, or retrograde fashion through the knee. It is found in multiple austere environments, and its user base is expanding [6]. Replacement nails and screws are provided gratis to the hospital, as long as patient data are entered in an online data base. It has the advantage to be free of charge to the patient. Volunteer surgeons are likely to be exposed to this system, and local surgeons are usually proficient in its use and excellent teachers [7].

The fracture age, pattern, and location will dictate the type of nailing: antegrade or retrograde and static or dynamic. Fresh fractures may require a small opening at the fracture so a finger can assess the reduction as reamers and the nail engage the distal fragment. The periosteum should be disturbed no more than necessary. Older fractures require more extensive exposure. An intact isthmus allows some degree of 3-point fixation, particularly for straight nails. Nails placed retrograde should end above the level of the lesser trochanter or more than 6 cm below it. The area in between is a high-stress area, and the patient may refracture at the level of the end of the nail or the interlocking screws. Dynamic nailing can be considered for simple, non-comminuted fractures of a stable pattern. Proximal shaft fractures should be done in an antegrade fashion, and distal shaft fractures in a retrograde approach. Comminuted, isthmic, long oblique, or segmental fractures should be nailed statically. Antegrade nailing is done in the lateral or semi (floppy)-lateral position; retrograde nailing is done with the patient supine with the knee flexed.

Bilateral femur fractures can be fixed during the same session in the supine position (Fig. 22.10). Ipsilateral femur and tibia fractures can both be nailed through a single medial parapatellar or transpatellar tendon approach. If a "triangle" (easily made in the hospital workshop) is available to support the femur, the closed tibia fracture can be nailed first, followed by the femur.

If the tibia fracture is open and external fixation will be the initial treatment, the ex-fix can be used for traction while fixing the femur. In this case, it is safer to redrape the ex-fix out of the field and re-prep the thigh. If the femur fracture cannot be secured by these methods, it should be addressed first. Once the femur is nailed, it is always possible to revisit the tibial reduction and adjust the external fixator as needed.

When the tibia will also be nailed, it can be temporarily immobilized with a two-pin single-bar ex-fix, a cast, or back slab draped out of the

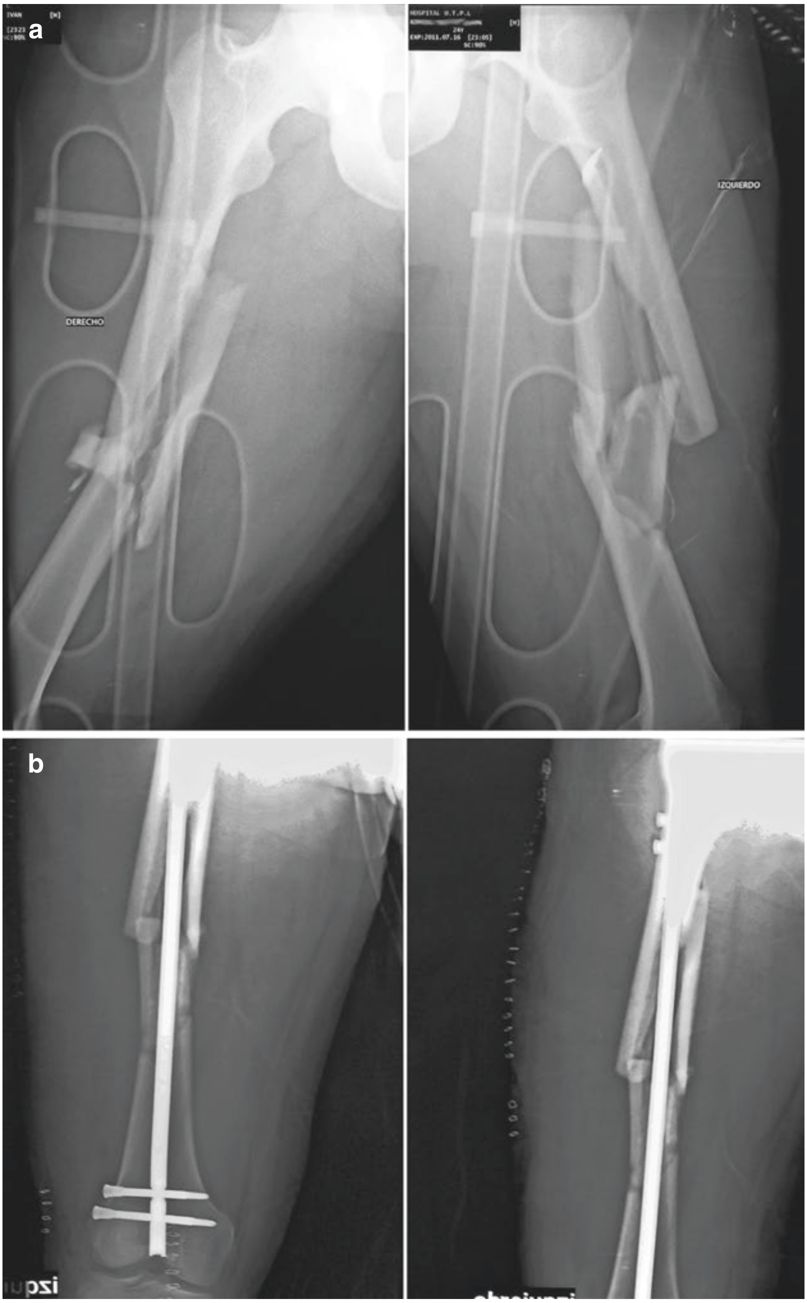

Fig. 22.10 (**a**) Bilateral closed femur fractures. (**b**, **c**) Bilateral retrograde SIGN nailing was done in the supine position

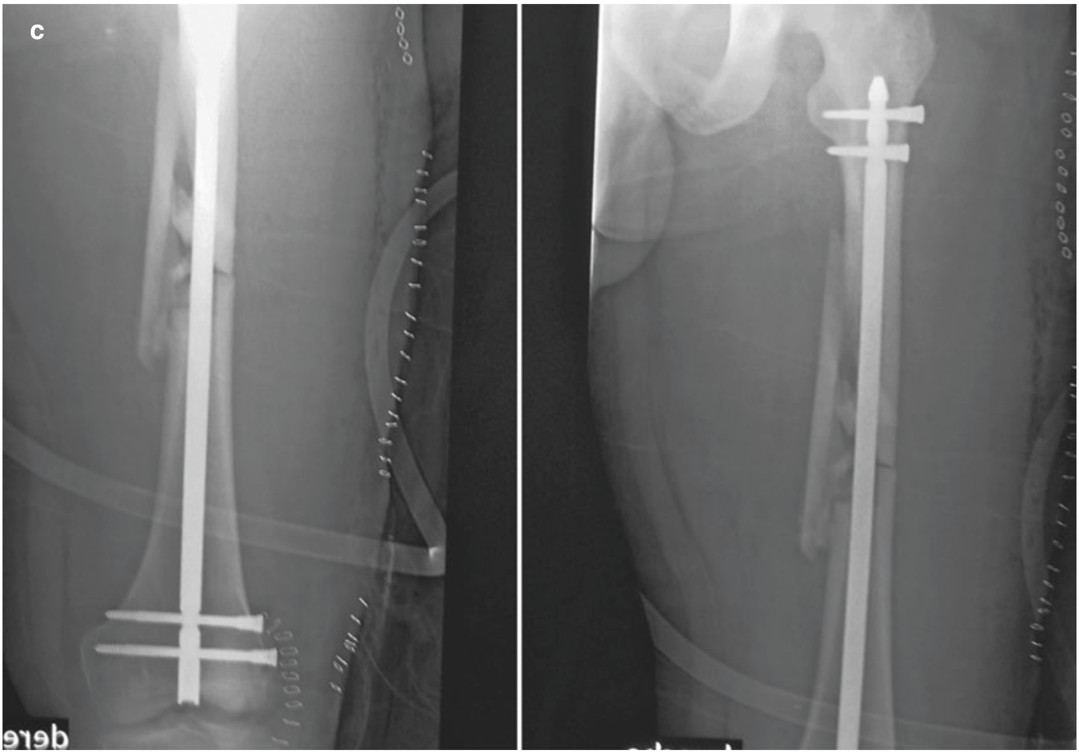

Fig. 22.10 (continued)

field and removed later or by tightly rolling two or three nails or long plates in sterile towels and securing them to each side of the leg with an Esmarch band or ace wrap to act as a stabilizing splint. A dried back slab can be placed in a sterile Mayo stand cover, secured on the leg, and removed after the femoral nailing is secured.

Intramedullary devices are not always available or affordable, and in many places, plate and screws are the only surgical options. Inexpensive implants are available almost everywhere, and it is not unusual for a patient to buy a plate and screws at a local pharmacy. More commonly, semi-standard large fragment sets are available in the hospital, although often with a hodgepodge of plates and screws of different sizes or metallic composition. If using a plate, apply it in the sub-muscular plane whenever possible, to preserve the periosteal circulation. The surgeon should be aware of available implants *before* surgery. Do not accept the word of the OT supervisor. Plates and screws that are too long can be cut, but the reverse is not true. The same is true for any hardware removal—make sure you have the appropriate screwdriver *before* you embark in what may be an extremely frustrating endeavor.

Newer technologies such as locking plates are rarely available. Still, principles of minimal periosteal stripping, indirect reduction, and sub-muscular sliding of the plate should apply when there is a large comminuted fragment. Standard DC plates are hard to contour properly without plate benders. Pliers, or ideally a vise grip, and a screwdriver or small curette or elevator placed through a screw hole along with a strong assistant and a healthy dose of enthusiasm will usually suffice. Large bone fragments can be fixed with lag screws, but cerclage wire is detrimental to the periosteal blood supply and should be avoided.

Postoperative management depends on many factors, not the least of which is patient compliance and collaboration [8]. Early weight bearing, at least partial, is rarely contraindicated when using an IM nail, and we encourage weight bearing as tolerated in most fractures that are interlocked. Active ROM of joints above and below the fracture is encouraged. A static nail that shows no or poor callus formation at 3 months could be dynamized distally, although no one agrees that it is effective or makes any difference. Many such fractures heal with more time. Established nonunions at 6 months showing no progression to healing require re-intervention: hardware removal and exchange, unless infection is present or suspected, in which case a few strategies need to be considered (see Chap. 41) [9].

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23 Trauma of the Distal Femur, Knee, Tibia, and Fibula

Richard A. Gosselin and David O. Oloruntoba

Fractures of the Distal Femur

Extra-articular Fractures

Isolated extra-articular fractures at or below the diaphyseal-metaphyseal junction of the distal femur are common. The management is challenging, and the results depend on the surgeon's experience and available resources. Rigid internal fixation of extra-articular fractures is the only way to allow early mobilization of both the knee joint and the patient, with all the known benefits of each.

Locking plates are rarely available. If a surgeon, by chance, has brought a set and uses it, the appropriate screwdrivers need to be left behind for the local surgeon. Even dynamic condylar screws (DCS) are rare. Old, often incomplete blade plate sets are more common, and our preferred technique for using these is described in Appendix 5. Depending on the amount and quality of the bone in the distal fragment, an eight- to ten-hole large DC plate can be bent through the fourth hole at a 90–95° angle, fashioning a blade plate—a challenging exercise if a plate bender is unavailable. If the bone quality of the distal fragment is adequate and the piece is large enough to accommodate three holes of a large DC plate, contouring it to fit the lateral cortex might suffice. A smaller second plate on the medial side can be added if the rigidity of the construct is in doubt.

Temporary fixation with crossed Steinmann pins can supplement the plate fixation. The pins are incorporated in a long-leg cast with the knee at 30–40° flexion to prevent weight bearing. The pins and cast are removed at 6 weeks, at which time gentle active range of motion (ROM) is started if fracture consolidation is progressing. Otherwise, continue the cast for another 4–6 weeks before beginning knee ROM. Resume weight bearing at 10–12 weeks postfixation.

Another older, but still relevant, fixation method uses first-generation smooth malleable IM nails, such as Ender and Rush nails. Their advantage is availability. They don't provide rigid fixation, but in stable reductions early knee motion can be instituted, and in unstable situations 3–6 weeks of plaster or traction may be needed. Two implants are inserted via openings in the medial and lateral femoral condyles and advanced simultaneously across the fracture. Take care to prevent nail back out which may lead to skin and soft tissue erosion. Ender nails have an eyelet near their tip where a small screw can be used for "interlocking." Burying the tips

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of the nails under the cortex makes removal more difficult.

When available, interlocked nails, such as the SIGN system described in Chap. 22, can be used in a retrograde fashion for both extra- and intra-articular fractures, provided there is enough bone stock. If there is an articular component, it is reduced and fixed first with cannulated screws or large fragment cancellous screws, followed by gentle insertion of the nail which is interlocked in the distal fragment. Over-ream as needed to allow nail passage without disrupting the condylar fixation. If interlocking is not possible in the proximal femur fragment, the nail should be long and thick enough to provide 3-point fixation through the isthmus (Fig. 23.1).

When hardware for rigid or semirigid internal fixation is unavailable, there are three options: external fixation, skeletal traction, or pins and plaster. If sound external fixation can be achieved without spanning the joint, it should be considered. Spanning the joint is no better than cast immobilization, with the added risk of pin track infection.

When there is no or minimal comminution, temporary nonrigid fixation with Steinmann pins incorporated in a long-leg cast—as detailed above but without the plates—is another alternative, provided fixation is secure enough to maintain acceptable alignment. Only remove pins and cast at 6 weeks if early callus is visible by x-ray. If in doubt, continue the pins and cast or hinged cast bracing another 4–6 weeks.

Proximal tibial skeletal traction is the last resort. It should be done on a Bohler-Braun frame, if available, to reduce the deforming forces of the gastrocnemii. This confines the patient to bed for 4–6 weeks, at which time the fracture should be clinically "sticky" and amenable to cast treatment for another 6 weeks.

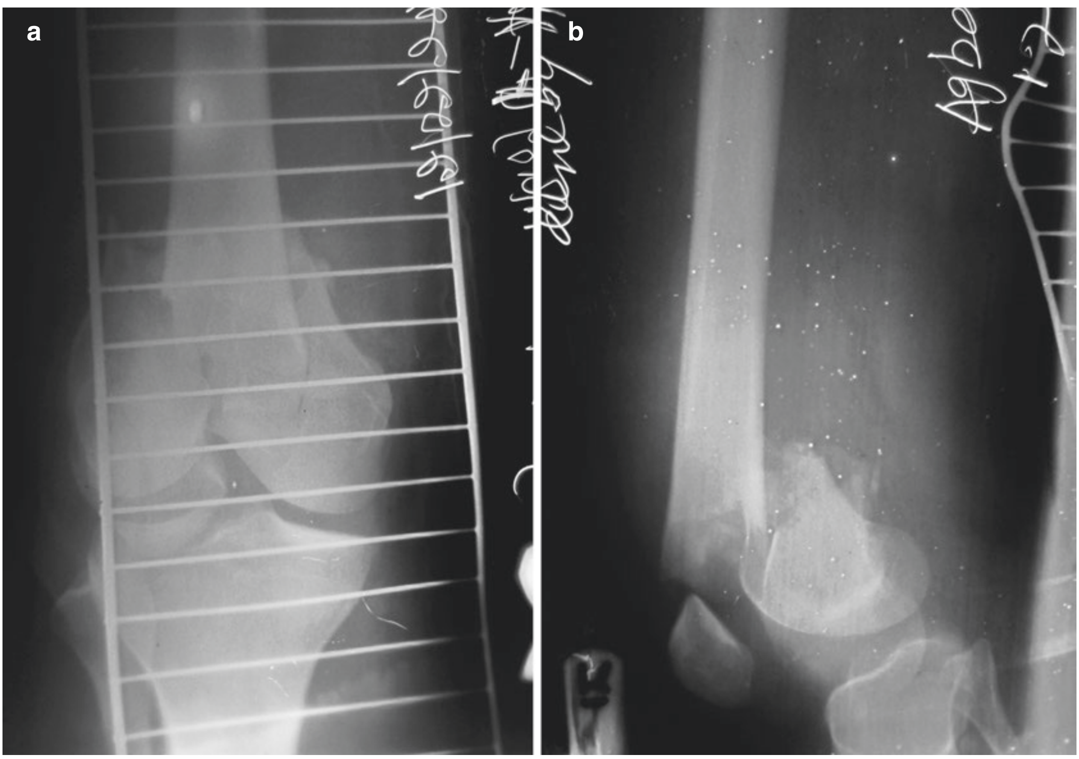

Fig. 23.1 (**a**, **b**) X-rays of a closed low Y-type intra-articular distal femur fracture. (**c**, **d**) ORIF by reestablishing the condyles with two compression screws and gentle insertion of a retrograde SIGN nail. Only one locking screw could be placed in the nail. Patient can do ROM exercises, but weight bearing is limited by the intra-articular fracture

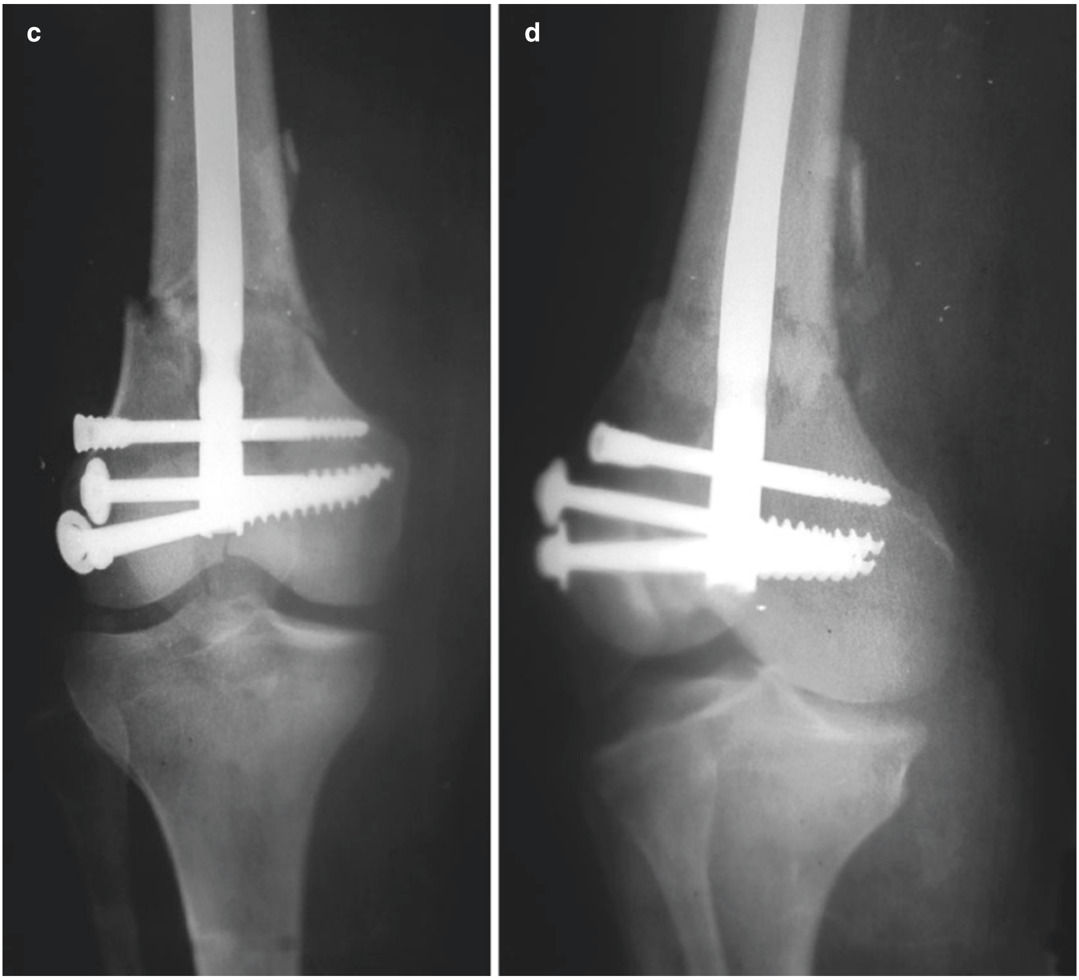

Fig. 23.1 (continued)

An alternative to conventional traction is the Perkins traction technique, in which active knee ROM exercises are started as soon as 3–4 days after the fracture and progressed as pain allows (see Chap. 13).

Intra-articular Distal Femur Fractures

Intra-articular distal femur fractures involve one or both condyles. An undisplaced intra-articular component can be difficult to diagnose, particularly with poor-quality x-rays. A high index of clinical suspicion mandates obtaining good-quality imaging. A knee hemarthrosis with fat droplets can give additional information, especially in undisplaced fractures. The principle of anatomic restoration of joint surfaces applies to the treatment of these fractures, and any step-off >2 mm should be treated. Hardware availability will determine the rigidity of the fixation and thus the post-op regimen.

Since screws, wires, and pins are almost always available, one can at least reduce and fix the joint surface as anatomically as possible and convert the fracture to an extra-articular one, to be managed as described above. Even if technically and biomechanically unsatisfying, a good articular reduction with lag screws and/or pins, even if not a rigid fixation, will significantly improve the long-term functional prognosis (Fig. 23.2).

The AO Foundation web site on distal femur fractures: https://www2.aofoundation.org/wps/portal/surgery?showPage=diagnosis&bone=Femur&segment=Distal.

Injuries of the Patella and Ligaments About the Knee

Patella Fractures

Management of patella fractures depends on the age of the injury, the amount of comminution or displacement, associated soft tissue injuries, and availability of hardware. Undisplaced patellar fractures can be treated in a well-molded, full-weight-bearing cylinder cast for 6 weeks.

Articular step-offs ≥2 mm should be treated surgically. Figure-of-eight tension banding over two parallel K-wires remains the gold standard (Fig. 23.3). When wire is not available, braiding three strands of heavy non-resorbable suture can provide a cerclage strong enough for tension banding. Be sure to test it intraoperatively.

Using the plastic sleeve from a 14 or 16 French Jelco IV catheter facilitates passing the tension band wire under the tendons, instead of through them. The K-wires should be bent at one end for ease of later removal under local anesthetic. Early active ROM and full-weight bearing (WB) are encouraged.

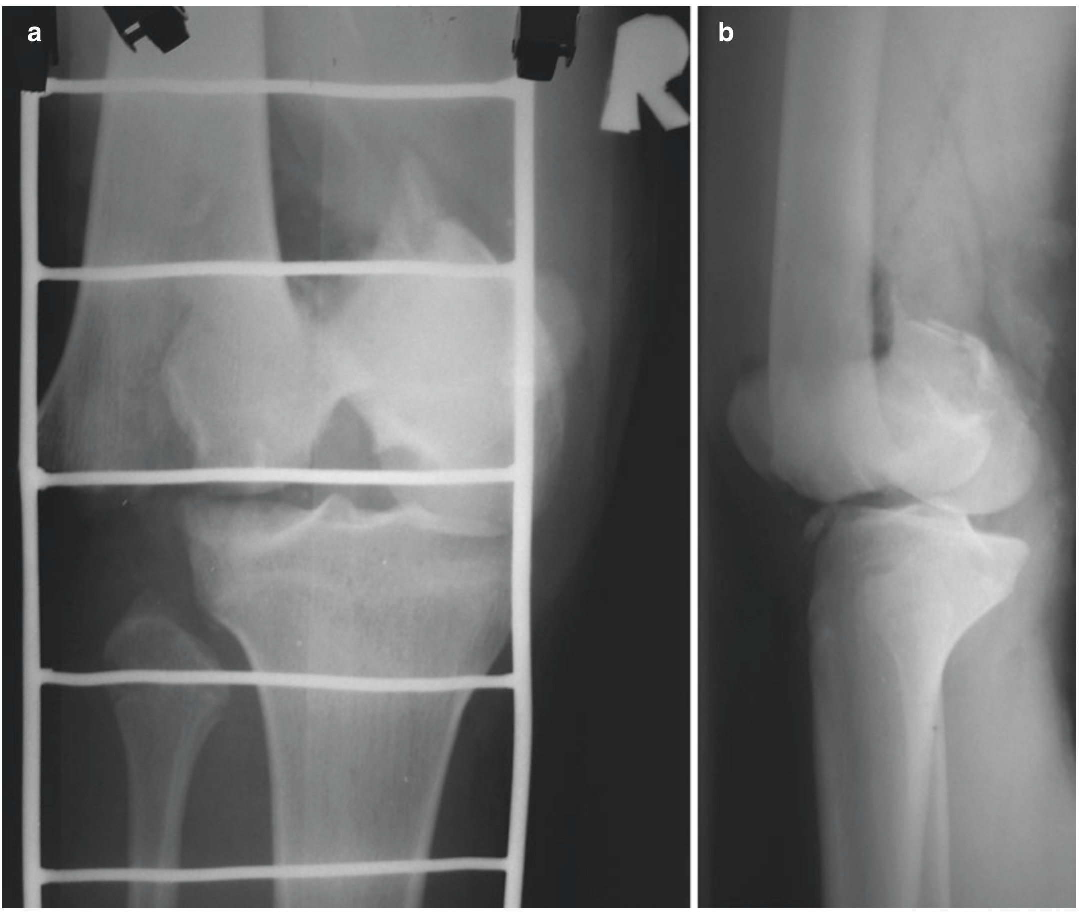

Fig. 23.2 Another way to treat a distal intra-articular fracture. (**a**, **b**) Admission AP and lateral x-rays. (**c**, **d**) Postoperative AP and lateral views showing inter-fragment compression of the articular components with one lag screw and temporary fixation of the extra-articular components with two crossed Steinmann pins that will be incorporated in a long-leg cast and removed at 6–8 weeks

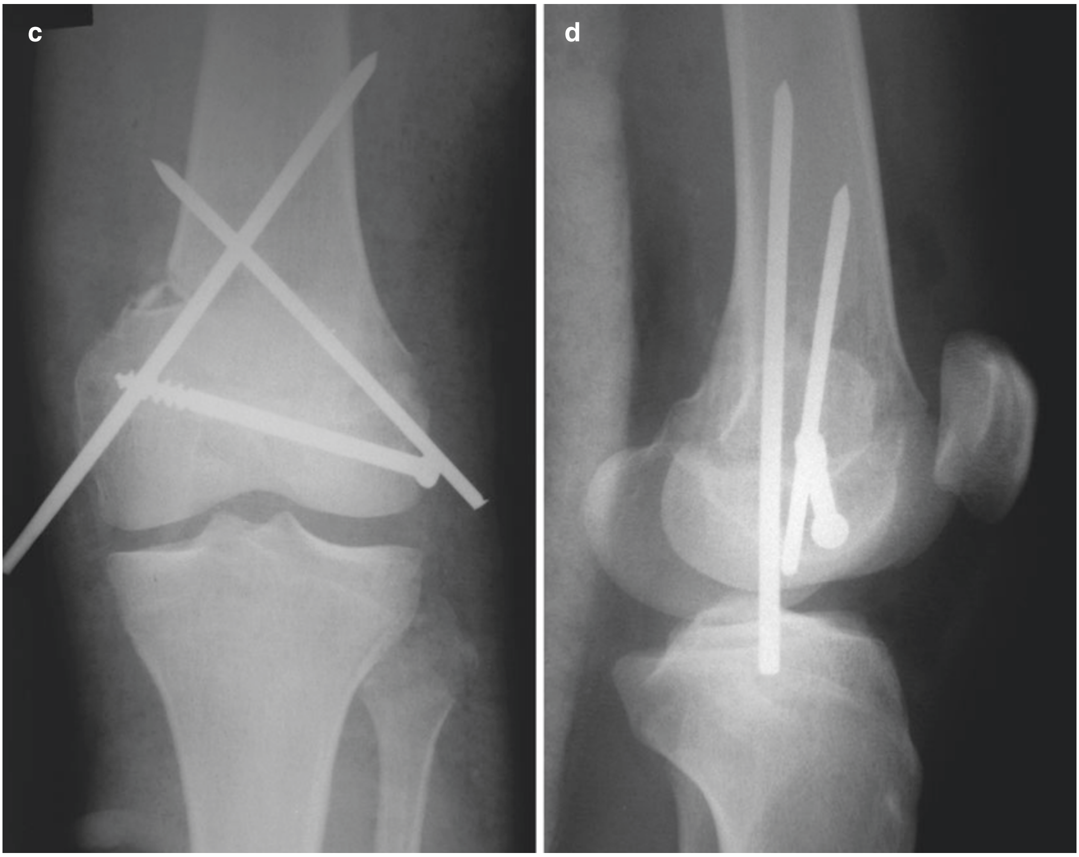

Fig. 23.2 (continued)

When one pole is comminuted beyond repair, a partial patellectomy with reattachment of the quadriceps or patellar tendon to the remaining patella with transosseous sutures is a good solution. Fresh, completely comminuted ("blown-up patella") fractures involving the entire patella should be treated initially by K-wire fixation of the main fragments and "containment cerclage" of the patella, to prevent further displacement. A cylinder cast is used for 3 weeks, after which gentle active ROM is started. Many patients will do well clinically despite radiographic evidence of some degree of mal-/nonunion. Total patellectomy can always be done later if patients are symptomatic. But they must be aware that pain may persist, and there will be residual weakness—a significant impairment for people living close to the floor. Whenever surgery is done, the surgeon should meticulously repair any associated lesions of the medial and/or lateral retinaculum.

Patellar nonunions may require only compression fixation with screws +/− tension banding if minimally displaced. Displaced nonunions are technically more difficult: significant soft tissue release may be necessary for end-to-end coaptation of the fragments. Small polar fragments are better excised than repaired, if symptomatic. The amount of pain or disability should dictate the need for surgery, not the x-ray appearance. The patient should be aware that the price to pay for surgical success of union is often some persistent stiffness (Fig. 23.4).

Quadriceps and Patellar Tendon Ruptures

Acute (up to 6 weeks old) rupture of the quadriceps or patellar tendons should be repaired surgically. Depending on the location of the rupture,

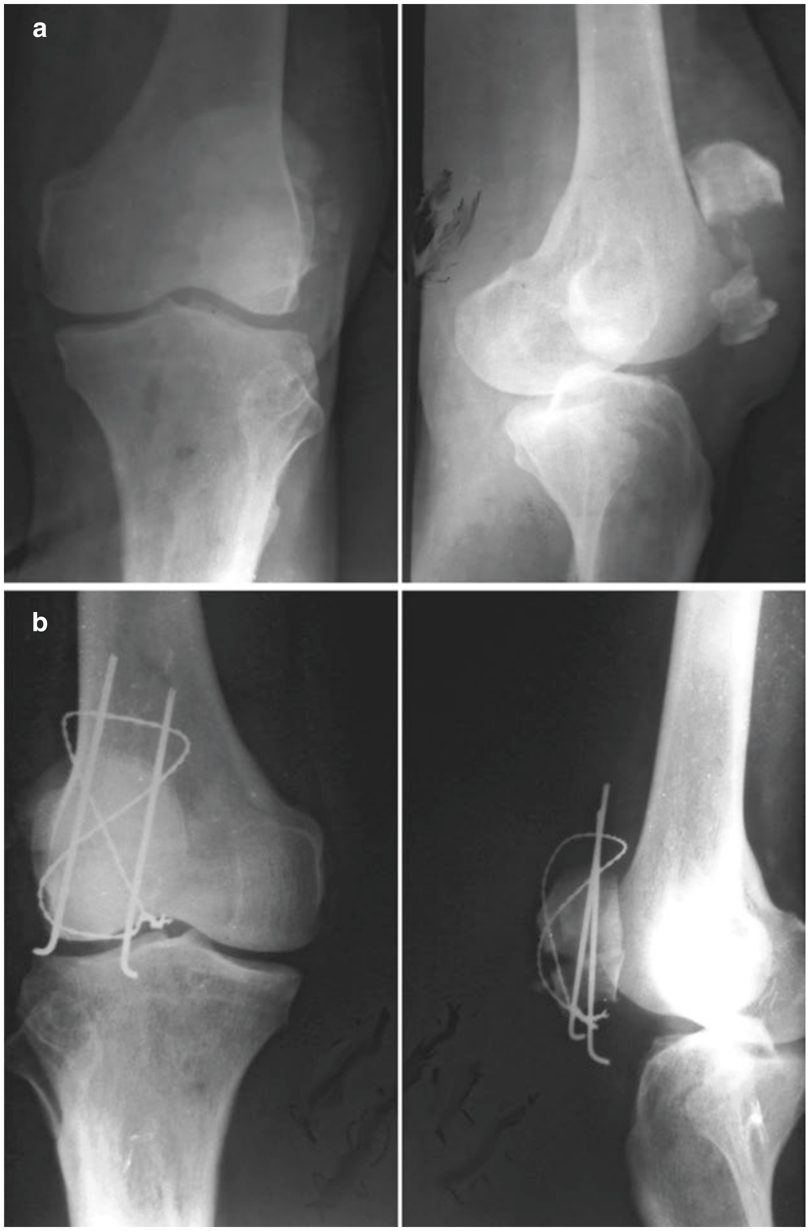

Fig. 23.3 (**a**) X-ray of displaced comminuted transverse fracture of patella. (**b**) ORIF with figure-of-8 tension banding, after excision of small comminuted fragments. Dental wire was the only wire available; two strands were braided together

transosseous sutures may be required. The repair should be protected in a well-molded cast in extension for 6 weeks, allowing full WB. Chronic ruptures require soft tissue mobilization, often tendon grafting, and extensive rehabilitation. Patients need to understand that there will be a trade-off between instability and stiffness.

The repaired construct may be augmented (our preferred technique) with a tendon or fascial graft tunneled transversally through the patella and woven through the tendinous remnant. The peroneus brevis (with proximal myo-tenodesis to the longus), palmaris longus tendon, or a strip of fascia lata can be used as graft. When doing an augmentation, it is preferable to tighten both the repair and the augmentation with the knee in maximum extension, tying the repair sutures first. The patella itself can be temporarily skewered to the distal femur or proximal tibia with a small Steinmann pin to relieve tension on the repair. A long cylinder non-weight-bearing cast is worn for 6 weeks after which time the Steinmann pin is removed and ROM started. If no Steinmann pin transfixes the joint, WB can start early in the cast. All these bone procedures on a weakened patella may create an iatrogenic fracture, which requires repair as described above.

Special consideration needs to be given to femur fractures undergoing open internal fixation after prolonged traction. Knee stiffness is common and often worsened by the relative lengthening of the extensor mechanism with the open reduction. Rigid fixation allows the knee to be manipulated, but this should be done with great care, and the goal should be modest. Any sudden "giving way" is suspicious of an extensor mechanism rupture, and clinical signs such as a palpable defect or lack of patellar motion warrant immediate surgical exploration and repair.

Patellar Dislocations

After reduction acute dislocations of the patella usually do well with nonsurgical management in a cylinder cast or an appropriate brace for 3 weeks. If on assessing postreduction stability, re-dislocation occurs spontaneously with knee flexion between 45 and 90°, surgical repair of the medial retinaculum and release of the lateral retinaculum will likely be needed. Patellae dislocated for more than 6–8 weeks do not relocate by manipulation alone.

Chronic patellar dislocations usually present with an extension lag, inability to independently squat or rise from the kneeling position, and varying degrees of pain. Instability and weakness may improve with surgical relocation that includes extensive lateral release, medial plication, and advancement of the vastus medialis. Although

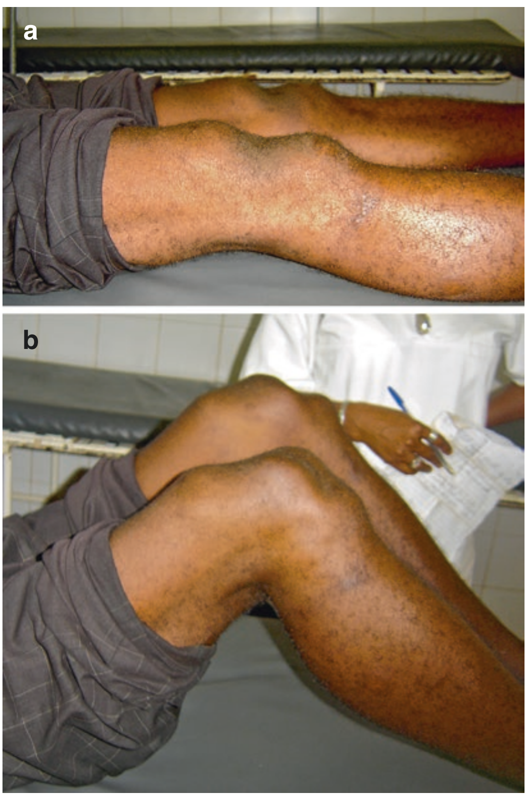

Fig. 23.4 (**a**, **b**) Clinical appearance of bilateral chronic patella nonunions with significant patella alta. X-ray appearance of (**c**) right and (**d**) left distal patellar pole nonunions with impressive proximal migration of the patellar body. This patient had the problem for years and had no pain but was unable to kneel or get up from the kneeling position without support. No surgery was offered

Fig. 23.4 (continued)

strength of the extensor mechanism will never be normal, the residual stiffness is usually better tolerated than the preoperative weakness and instability. Chondromalacia sets in early when the patellar cartilage has been damaged, and even a stable open reduction of a chronic patellar dislocation does not guarantee pain-free function. When pain is a major problem, a total patellectomy with realignment of the extensor mechanism might be the only option. Long-standing dislocations where the main symptom is weakness, not pain, and the patient is able to function adequately are better left alone (Fig. 23.5).

Ligamentous Injuries of the Knee

The results of surgical repair of acute or chronic tears of knee ligaments are highly dependent on postoperative rehabilitation and bracing, both of which are rarely present in low- and middle-income countries (LMICs). Acute injuries with displaced bony avulsions of the origin or insertions of ACL or PCL or the biceps tendon or lateral ligament from the fibular head are best treated by open surgical fixation. Associated meniscal lesions should be resected or repaired depending on the site and type. The knee should

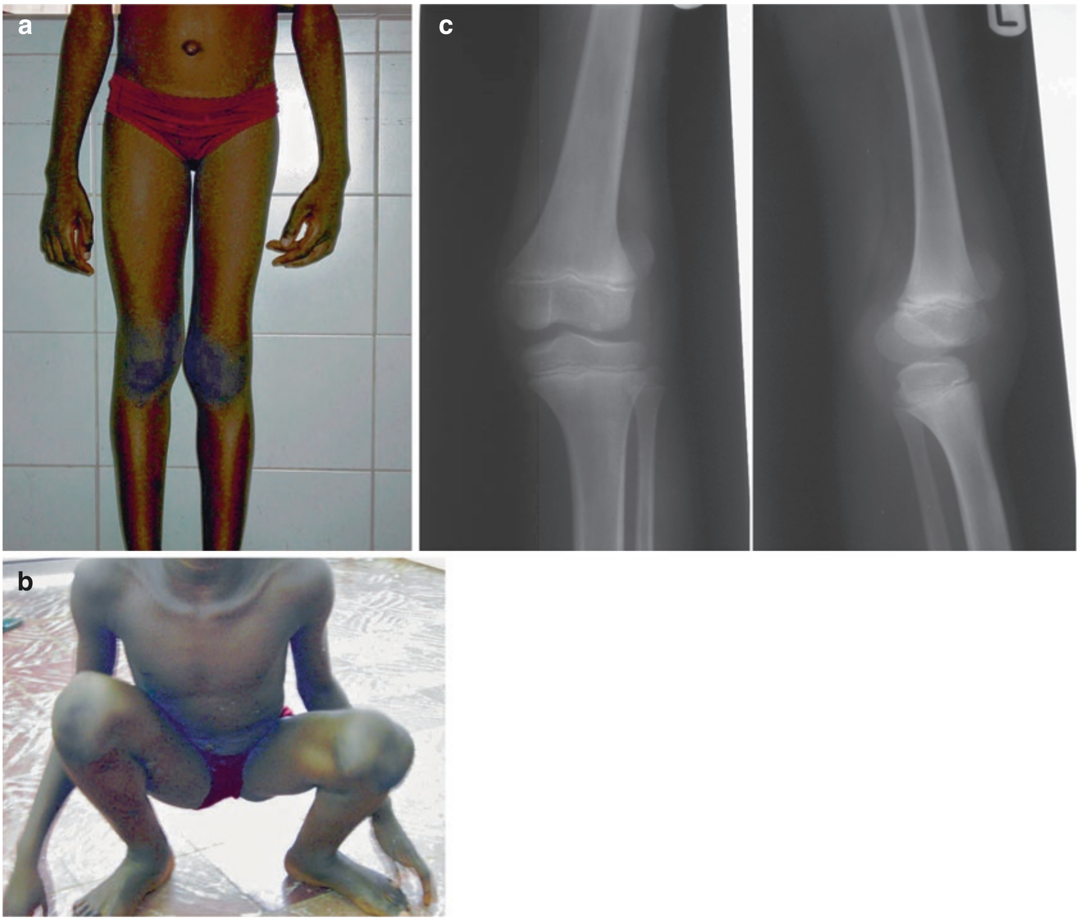

Fig. 23.5 (**a**) Clinical appearance of a chronic dislocation of the left patella. (**b**) This young man is able to squat and rise independently. Note that right thigh is better muscled than the left. (**c**) X-ray appearance of chronic left lateral patellar dislocation. No surgery was offered

be immobilized in a non-weight-bearing long-leg cast for 3–4 weeks at 30–40° flexion, after which time active rehabilitation is started. Progressive weight bearing can begin 2–3 weeks later. Commonly, patients are instructed on an exercise regimen to do at home and will never be seen again. This regimen leaves a knee that is initially stiff, but young, determined patients will have regained most of their pre-injury function at 1 year. Pure ligamentous injuries are usually better left alone, unless the ideal circumstances are all present. The same applies to chronic ligamentous instabilities.

Dislocations of the Knee

Acute Knee Dislocations

Acute knee dislocations should be reduced as soon as possible after the aseptic evacuation of any hemarthrosis. The patient must be kept under observation for frequent and regular monitoring of the neurovascular status since a compartment syndrome can appear even after reduction, and an intimal tear of the popliteal artery can quickly lead to acute thrombosis and distal ischemia. A vascular injury will most often require surgery, and unless a vascular surgeon is quickly available or the orthopedic surgeon has the skills and equipment necessary, these injuries often lead to an above-knee amputation.

Subacute Knee Dislocations

Subacute knee dislocations are usually posterior and present beyond the period of vascular risk. They can often be reduced closed under anesthesia. Beyond 3 weeks and up to 3 months, open reduction is usually necessary, and care should be taken not to injure the popliteal neurovascular bundle posteriorly. On rare occasions, a closed reduction is possible, but it is necessary to confirm anatomic reduction with good AP and lateral views, as residual subluxation is not uncommon and should be dealt with surgically (Fig. 23.6). Residual instability is often complex and cannot be handled by casting only. Temporary transfixion with two crossed Steinmann pins for 6 weeks can avoid the knee healing in a subluxed position. The knee should be immobilized in slight flexion to reduce traction on the popliteal vessels. With dislocations older than 3 months, the amount of shortening and scarring usually precludes a safe reduction, and a knee fusion is preferable (Fig. 23.7).

All knee dislocations require an aggressive physical therapy regimen with an emphasis on strengthening the stabilizing musculature, not just regaining range of motion.

Fractures of the Tibia and Fibula

Tibial Plateau Fractures

Undisplaced tibial plateau fractures can be treated nonoperatively, after sterile evacuation of the hemarthrosis, in a non-weight-bearing long-leg cast in 20–30° flexion for 6 weeks, followed by an additional 6-week non-weight bearing accompanied with ROM and strengthening exercises. Compliance might be an issue as by the time the cast is removed, there is little pain, and patients are eager to resume normal activities.

Fresh fractures displaced ≥2 mm should be treated according to the universal principles of anatomic reduction, rigid internal fixation, and ± subchondral graft support. With fluoroscopy, simple non-comminuted fractures can be treated percutaneously with cancellous screws. Most often, open reduction, lag screw fixation with one or occasionally two neutralization plates is needed. Fixation should ideally be rigid enough to allow early joint mobilization. ACL/PCL bony avulsions should be secured with tunneled sutures or lag screws. Meniscal lesions should be repaired or excised; mid-substance ligament tears can be repaired primarily but generally not augmented.

Where plates are not available, the only option may be to restore the articular surface with screws or even pins and treat the now extra-articular fracture in a long-leg cast (Fig. 23.8). If length needs to be restored, one can use pins in plaster in distraction from distal femur to tibial shaft or a spanning ex-fix. Pins remain for 4–6 weeks, but weight bearing is delayed at least 6 weeks and gradually progresses to full WB over the following 6 weeks. Neglected fractures with malunions and articular incongruence rapidly lead to degenerative changes, often with some angular deformity (Fig. 23.9). On occasion, varus or valgus realignment osteotomies are indicated, but more often the only option is a knee fusion as replacements are rarely available and/or affordable (see Chap. 41) (https://www.vumedi.com/video/orif-of-bicondylar-tibial-plateau-fractures/; https://www2.aofoundation.org/wps/portal/surgery?showPage=diagnosis&bone=Tibia&segment=Proximal).

Fibula Fractures

Isolated fractures of the fibula occur from a direct blow to the lateral aspect of the leg and are rare. Once a compartment syndrome has been ruled out clinically, treatment is symptomatic. It is mandatory to examine the ankle joint to rule out an injury around the medial malleolus, suggestive of

Fig. 23.6 (**a**, **b**) X-rays of fresh posteromedial dislocation of the left knee. (**c**) Unacceptable residual opening of the lateral compartment after closed reduction. This required a repeat closed reduction and temporary joint transfixion with two Steinmann pins for 6 weeks

Fig. 23.7 AP and lateral x-rays of a 2-year-old dislocation of the knee without neurovascular loss. The patient was able to hobble with a walking stick

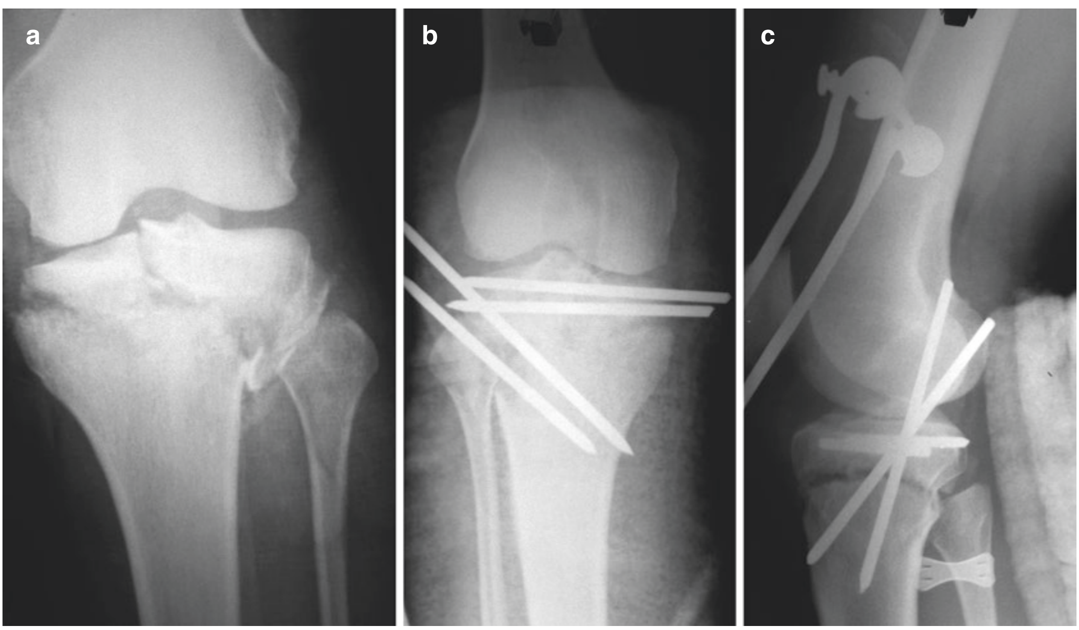

Fig. 23.8 (**a**) A comminuted T-type fracture of the proximal tibia, (**b**, **c**) treated with Steinmann pins to reduce and fix both intra- and extra-articular components. The distal femoral traction pin (which was inserted too proximally) is used to treat an associated femoral shaft fracture

Fig. 23.9 (**a**) Clinical appearance of varus right knee secondary to 1-year-old untreated and malunited medial tibial plateau fracture. (**b**, **c**) Pre-op X-rays show joint irregularity and deformity. (**d**, **e**) Post-op X-rays show reconstitution of tibial articular surface, with slight central step-off and pinning of joint (Steinmann pins would have been preferable to K-wires) to hold position. Note narrowing of medial side of joint and early changes consistent with DJD

Fig. 23.9 (continued)

a Maisonneuve type of injury (the so-called high ankle sprain). Tears of the deltoid ligament and syndesmosis lead to instability and widening of the mortise which can be demonstrated with stress x-rays in valgus (pronation, abduction). Mortise widening ≥2 mm is an indication for a syndesmosis screw. The alternative is a long-leg cast with the foot in varus and a few degrees of equinus. At 3 weeks, the cast is converted to a full-weight-bearing PTB-type cast for three more weeks with the foot in a neutral position.

Tibial Shaft Fractures

Conservative management with casts and functional bracing has become a lost art in rich countries, as internal fixation has demonstrated significant early personal and societal benefits. Long-term advantages of surgical treatment in developing countries are more debatable [1].

In LMICs, conservative management remains the treatment cornerstone of closed and Gustilo type 1 open fractures. With acceptable reduction, most patients will heal and recover full function. Criteria for acceptable alignment are not universally agreed upon, but most surgeons accept that at least 50% bony contact in both AP and lateral projections and no more than 5° angulation in the sagittal and coronal planes are acceptable [2].

Undisplaced transverse mid-shaft fractures can initially be treated in a weight-bearing PTB or BK cast. Sequential X-ray monitoring is required.

A satisfactory closed reduction of an initially displaced fracture can be immobilized in a non-weight-bearing well-molded long-leg cast (LLC) with 20–30° knee flexion. With fluoroscopy, reduction can be done under direct vision. When there is no assistant to help and the fracture is unstable, temporary fixation with a percutaneous Steinmann pin frees the surgeon's hands to apply the cast. The pin is removed once the cast has hardened—the "disappearing or vanishing pin" trick.

Fracture alignment is monitored regularly with sequential x-rays. Unacceptable displacement requires a repeat reduction and new cast or cast wedging. For surgeons who rarely use nonoperative treatment, cast wedging, also called gypsotomy, can be a remarkably useful technique to maintain or correct unacceptable angulation (see Chap. 13).

At 6 weeks or when the fracture is clinically "sticky," as shown by painless stress on the leg at the fracture site, the LLC is converted to a below-knee weight-bearing cast, preferably a patellar-tendon-bearing type to limit rotation of the proximal fragment and give added stability against varus and valgus stresses (see Chap. 13). X-rays and clinical examination out of the cast after 6 more weeks will determine the need for longer immobilization. Muscle atrophy in the cast is reduced by static exercises in plaster.

This generic management scenario will vary according to many factors: fracture pattern and degree of comminution, high- vs. low-energy mechanism, associated injuries, and comorbidities. Fractures at the proximal tibial metaphyseal-diaphyseal junction, especially when comminuted, are notoriously slow to heal and may require extended immobilization in a weight-bearing, above-knee cast. X-rays are important indicators of healing but are costly. Examination for tenderness, mobility, or a rubbery feeling when the fracture is stressed and the ability to bear full weight without a limp or hesitation are important parameters when assessing final cast removal. Solitary fractures of the tibia with an intact fibula can pose problems of varus and delayed union and need to be followed closely.

The drawbacks of cast immobilization—joint stiffness, muscle atrophy, and weakness—can be minimized with internal fixation but at a higher risk of infection. Classical closed interlocked nailing is difficult without fluoroscopy (see technique in Appendix 5).

The SIGN nailing system is designed for use in environments with limited resources [3, 4]. It uses a solid nail that can be inserted with the patient on a regular table, opening the medullary canal with hand reamers. Proximal and distal interlocking are achieved using the rigid external target arm (Fig. 23.10). As many tibial shaft fractures present late, an open reduction is usually necessary. Fresh fractures on the other hand pose more of a dilemma, giving the surgeon choices of blind closed nailing, open nailing, or nonsurgical management. Potential risks and benefits of these options are well known, but financial and educational considerations, or operating room status, need to be factored in.

If forced to nail a fresh fracture without fluoroscopy, small access incisions can be used to insert elevators and achieve reduction before passing the SIGN nail. Rotational reduction can be assessed by "eyeballing" the ASIS—patella—second metatarsal alignment.

Ender and Rush nails offer alternative internal fixation. They can be inserted using smaller incisions than plates and are easy to remove. They need precise bending as they provide fixation by three-point contact. A minimum of two implants should be used. Because of their poor rotational control, postoperative plaster support with a PTB is needed for the first 3–6 weeks.

In most cases, plates and screws are a poor alternative to IM nailing. But they are sometimes the only surgical option. Large fragment plates are big and bulky and too prominent to be applied on the medial border of the tibia. In applying them laterally, the surgeon should be careful to avoid unnecessary periosteal stripping and aim for a submuscular positioning.

In the rare instance where no internal fixation is available and the fracture too unstable for cast treatment, the only other option is some form of external fixation. This can be achieved with a true external fixator or with pins and plaster—poor man's ex-fix—in which transfixing Steinmann pins are inserted above and below the fracture site, the fracture reduced, and the pins incorporated in an above-knee cast. Some surgeons prefer to use a third pin in one of the fragments to better control rotation.

Fractures of the distal tibia can be treated by "pins and plaster" using an ankle-spanning calcaneal pin. The cast is first applied from the tibial tuberosity to just below the malleoli, to secure the pins, and then completed above the knee and distally with the foot in neutral position.

Fresh open fractures are surgically debrided, but previously neglected small open fractures with quiescent, scabbed wounds are left undisturbed. Wounds can be managed by windowing or bivalving the cast. After the wound has closed,

Fig. 23.10 (*Left*) Surgeons inserting a SIGN nail in a closed fashion using gravity assistance. (*Right*) Inserting a distal screw medially through the rigid target arm

the windowed or bivalved cast can be sealed. (See Chap. 13 for windowing plaster casts).

Most grade 2 and all grade 3 fresh open tibial fractures should be treated with surgical debridement and external fixation. Often the "external fixation set" is a hodgepodge mixture of pins, clamps, and rods from different sets, and the surgeon's improvisational skills may be put to the test. When possible, pins should be inserted through healthy skin, keeping in mind that they should not interfere with future flaps or skin grafts. The pins and plaster technique can also be used for some type 2 injuries and the cast windowed over the wound. If external fixation is not possible, large wounds are best managed in calcaneal or distal tibial traction with a posterior back slab on a Bohler-Braun frame.

Whatever the indication for the use of external fixation, it is important to realize that its main role is to manage the soft tissue injury, not the bone. As soon as soft tissues are healed, by whatever means, the external fixator becomes superfluous. It should be removed before pin tracts become infected, and definitive treatment of the bone injury continues in a cast with or without weight bearing. If an additional surgical procedure is needed, it is safer after a "pin holiday," in which the ex-fix is removed, the pin sites curetted, and the extremity casted or placed in traction for 10–14 days [5] before the next surgical procedure. White cell counts, ESR, and CRP measurements after the "pin holiday" may help assess the potential risk for infection in anticipation of an ORIF.

The surgeon should pay particular attention throughout the entire period of external fixation to prevent equinus deformity of the foot and ankle. Unfortunately, this iatrogenic problem is seen far too often and significantly complicates the rehabilitation and often affects the final outcome more than the index injury. It is unfortunate as it is easily preventable with active exercises; active-assisted exercises with straps, belts, stockinet, or elastic bandage or bands; the passive use of a foot-plate connected to the ex-fix with string or elastic bands; or even a full BK back slab. Early ex-fix removal and replacement by a cast with the foot in neutral position is extremely important in preventing this debilitating complication. If a fracture is treated with an external fixator, it is totally appropriate to add a pin in the mid-foot or the first ray and incorporate it in the construct at 90° of ankle dorsiflexion. This pin can be loosened daily from the frame for active exercises of the ankle and re-secured in good position afterward (https://www2.aofoundation.org/wps/portal/surgery?showPage=diagnosis&bone=Tibia&segment=Shaft).

Bumper Injuries

Pedestrians are major victims in austere environments [6]. What often look like minor bumper injuries over the anterior leg without bony involvement can become nasty wounds, especially if a degloving component is present. These injuries must be handled aggressively and usually involve multiple surgical procedures (Fig. 23.11).

The Severely Mangled Leg

Such injuries are a challenge at home, where resources in vascular and plastic surgery, VAC wound systems, and sophisticated rehabilitation are all available. In LMICs, prolonged disability and pain from a tibial nonunion with severe soft tissue loss, requiring multiple, staged surgeries, are much more incapacitating than a well-fashioned amputation with a decent prosthesis. Many trauma patients are young males feeding extended families with blue-collar work or subsistence farming, who cannot afford years of inactivity. Most places now have some access to prosthetic facilities through NGOs, albeit not always timely or convenient. Sociocultural attitudes toward amputation need to be factored in and often take precedence over pure clinical considerations. Nevertheless, in general, surgeons working in resource-poor environments should be more aggressive with amputation of dysfunctional limbs than they might be at home.

Fig. 23.11 A low-energy bumper injury of the anterior tibia with necrosis of skin and fat. These injuries can be very difficult to treat, especially in obese patients and when thorough debridement is delayed

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24 Trauma of the Ankle and Foot

R. Richard Coughlin
and Raphael Kumah-Ametepey

Introduction

The incidence of lower leg, foot, and ankle fractures, dislocations, and injuries presents an enormous challenge to orthopedic clinicians and practitioners especially in less-resourced countries [1]. Fortunately, the vast majority of these injuries are low energy and can be treated successfully with closed methods of splinting or plaster of Paris (POP). As many of these fractures are intra-articular, inadequate or poor treatment can result in significant morbidity, disability, and loss of livelihood. Due to the lack of robust soft tissue coverage to the lower leg, foot, and ankle, well-intentioned operative procedures can result in disastrous infections or wound healing problems. The most important principle of treatment is to achieve a stable plantigrade foot while avoiding complications.

General Treatment Principles

The early and timely reduction of fractures and dislocations about the ankle and foot cannot be overstated. The soft tissue envelope is not tolerant of displacement or deformity, and expedient reduction will limit any swelling and skin pressure. A well-applied, well-padded back slab, U-splint, or bivalved POP with elevation is frequently the most important early management for the vast majority of these injuries.

The ultimate goal of treatment is to attain a plantigrade foot—without gait-disturbing varus, valgus, or equinus deformities (Fig. 24.1)—while preserving a healthy soft tissue envelope. A stable ankle mortise is essential for long-term ankle function. Instability from a shortened fibula, widen mortise, or translation/angulation of the talus will ultimately lead to post-traumatic arthrosis. In this regard, the most important parameter is the maintenance of the talus in line with the mechanical axis of the tibia in both AP and lateral planes.

If the position cannot be held by external splinting, casting, or cast modification by wedg-

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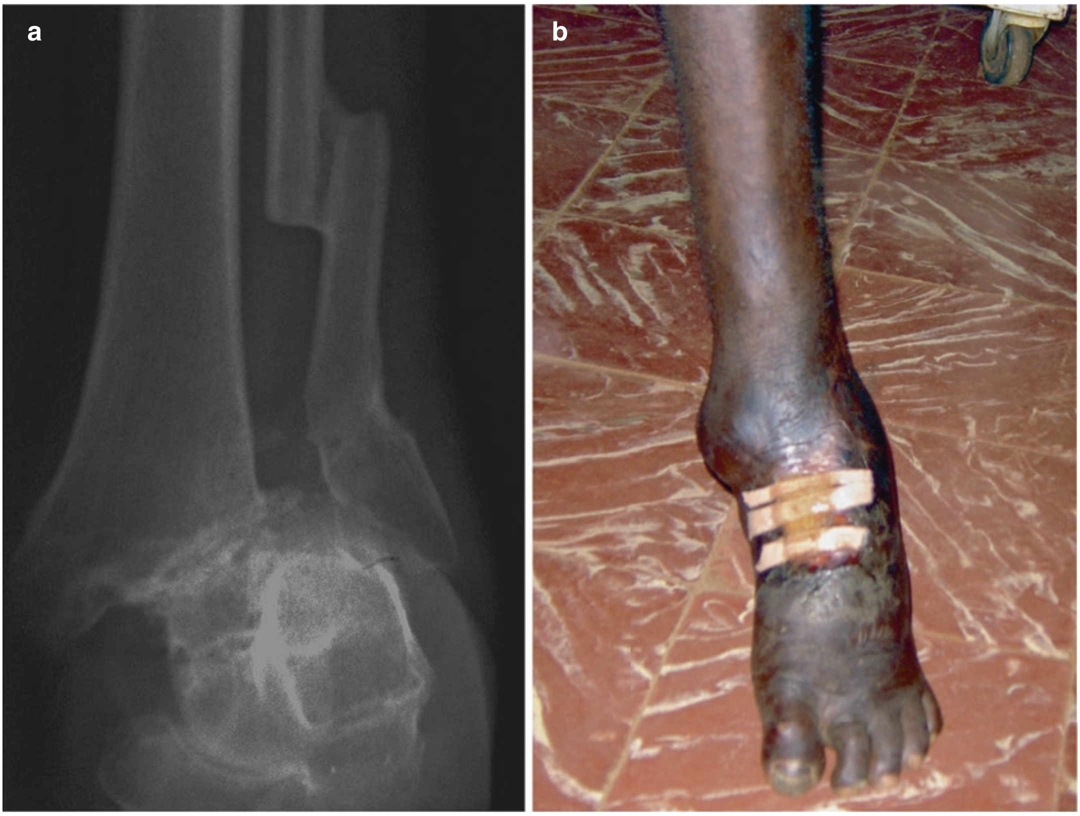

Fig. 24.1 (**a**) Malunion of a fracture/subluxation of the left ankle with lateral subluxation of the talus and valgus deformity. (**b**) Clinical appearance of the foot with a chronic wound on the dorsum secondary to ill-fitting shoes

ing or serial casting, open reduction and internal fixation (ORIF) should be considered after swelling has subsided and the skin shows fine wrinkles over the foot dorsum, fracture blisters have dried, and the soft tissue envelope has reached its optimal post-injury condition. The time until these changes occur depends on the time from injury to first hospital treatment, previous traditional treatments, the energy of the injury, and patient and nursing compliance. Wound dehiscence and infections around the foot and ankle are poorly tolerated in any environment, making it safer to wait. In less-resourced locales, lack of plastic surgeons and many antibiotics preclude effective management of wound complications (Box 24.1).

If ORIF is not possible in the face of uncontrolled instability, percutaneous pinning, especially in an attempt to hold alignment, can be considered. Its major drawback is the requirement of C-arm.

Box 24.1 Principles for Foot/Ankle Trauma

- Early/timely reduction of fractures and dislocations
- Immobilization with POP/cast
- Ultimate goal
  - Plantigrade foot
  - Stable ankle mortise
- Consider traction, ex-fix, or percutaneous pins

Intra-articular Distal Tibia Fractures (Pilon or Plafond Fractures)

By definition, intra-articular distal tibia fractures or pilon fractures infer a high-energy mechanism of injury, with soft tissue compromise and the potential for significant soft tissue and joint complications and long-term disability. The prudent approach in less-resourced environments should be avoidance of complications while addressing the basic principles of ending with a stable, plantigrade foot, and acceptable alignment. Calcaneal pin traction with elevation on a Bohler-Braun frame provides a safe and effective treatment without the unacceptably high soft tissue complications of open reduction and internal fixation with nonspecific plates. This technique, while relieving the deforming force of the Achilles tendon, utilizes ligamentotaxis to realign the major fragments and restore an acceptable ankle mortise. Direct access to blisters, open wounds, or other soft tissue injury allows observation and dressings. Take care to protect the heel from excessive pressure by a sponge under the Achilles or a glove partially filled with water.

After 2–4 weeks, this approach can be converted to pins and plaster or a spanning external fixator (Fig. 24.2). In certain fracture patterns or

Fig. 24.2 Typical spanning external fixator, with a transcalcaneal pin and a pin in the first metatarsal, maintaining the foot and ankle in neutral alignment

Fig. 24.3 Fracture of distal tibia and fibula fixed with Rush rods

clinical situations, small incision approaches may be used with the addition of K-wires, Rush rods, or small plates in order to optimize the position or stability of major fracture fragments or malleoli (Fig. 24.3). The decision to proceed with more rigid fixation and larger soft tissue exposures to achieve anatomic reduction should be taken with trepidation, but the results of neglected displaced pilon fractures are also well known [2] (https://www2.aofoundation.org/wps/portal/surgery?showPage=diagnosis&bone=Tibia&segment=Distal).

Ankle Fractures and Dislocations

Low-energy rotational ankle fractures and fracture-dislocations are common, and the majority can be adequately treated with closed methods (Fig. 24.4). Conversely, malalignment and mismanagement of these fractures result in pain, stiffness, or deformity, leading to severe functional disability. There

Fig. 24.4 (**a**) X-ray of closed bimalleolar fracture-dislocation after RTC. (**b**) Postreduction X-ray. (**c**) The appearance of the plaster cast showing molding distal to the lateral malleolus, proximal to the medial malleolus, and proximally around the fibula to produce three-point fixation (*arrowheads*). The heel is molded by lifting it in a plantar and forward motion to prevent equinus and maintain talotibial alignment (*arrowheads*)

Fig. 24.4 (continued)

are multiple classification systems (Lauge-Hansen, Weber), but the majority of displaced ankle fractures can be divided into (1) abduction-external rotation and less commonly (2) supination-adduction. Early reduction maneuvers are based on reversing the mechanism of injury and deformity. A prompt reduction will significantly reduce the pain, relieve neurovascular compromise, restore the plafond, and markedly reduce soft tissue swelling. Early reduction has a higher likelihood of success (https://www.vumedi.com/video/ankle-anatomy-and-radiology/).

In less-resourced countries, many of these injuries will present in a delayed fashion with significant swelling. An excellent approach to this problem is Quigley stockinette traction for those fracture deformities that arise from abduction-external rotation forces (the vast majority). The elevation and stockinette traction allow the swelling to resolve, and while in the stockinette, the foot and ankle fall into adduction, internal rotation, and supination by simple gravity (Fig. 24.5). After 5–7 days, this technique can be followed by a more securely molded cast for the maintenance of reduction after the swelling has subsided.

The reduction of malleolar fractures is eloquently described by Sir John Charnley in *The Closed Treatment of Common Fractures*, and we recommend that surgeons, especially those who haven't treated ankle fracture-dislocations by other than open means, review his chapter on Pott's fracture. He lists three common sources of error when attempting a reduction:

- Keeping the foot at right angles to the leg by dorsiflexing the forefoot in order to secure a plantigrade foot. This simply pushes the talus posteriorly, especially if the Achilles tendon is tight. Lifting the heel and bringing the hindfoot into a plantigrade position will correct this error (Fig. 24.6).
- Compressing the mortise in an attempt to reduce the diastasis and realign the talus will simply put pressure on the soft tissues. To reduce a bimalleolar fracture-dislocation, lateral pressure must be applied distal to the lateral malleolus, and medial pressure must be directed proximal to the medial malleolus, forcing the talus medially (Fig. 24.7).
- Incorrect rotation of the foot. The fracture forces produce external rotation, making it essential to keep the foot internally rotated to achieve a good reduction. Clinically check the alignment of the line connecting the patella with the second ray.

Fig. 24.5 Quigley stockinette technique for reduction and suspension of ankle injuries. Definitive operative or nonoperative management can be done when the swelling is reduced

In environments with no intraoperative or portable X-rays, let alone fluoroscopy and CT scan, the surgeon requires a sensitive touch and keen eye.

If unable to achieve and maintain an acceptable reduction, open reduction and internal fixation of ankle and foot fractures may be considered if an adequate host, appropriate operating room facilities, and reasonable hardware are present. Good visualization is neces-

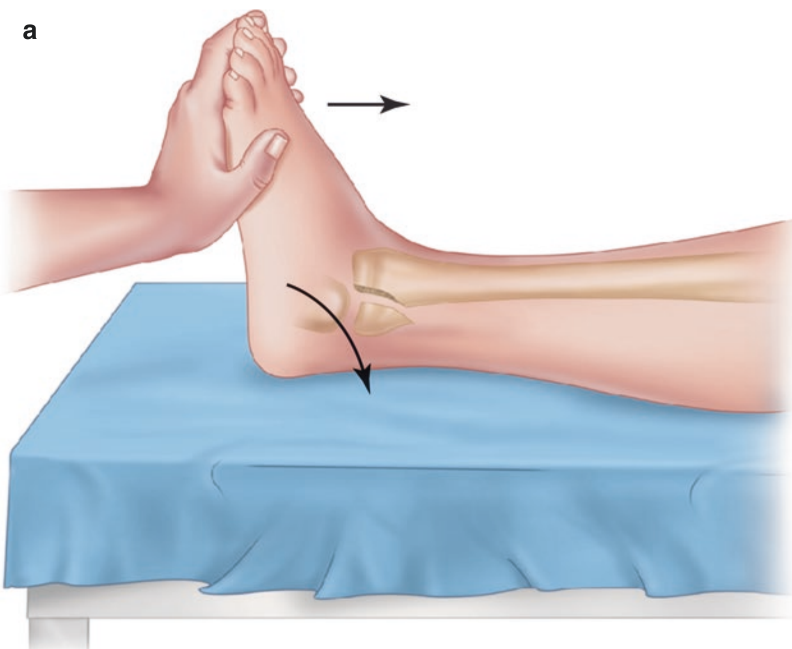

Fig. 24.6 Dorsiflexion of ankle fracture-dislocation with posterior injury is best performed by grasping heel and pulling it forward while dorsiflexing. (**a**) Reduction of an ankle fracture-dislocation with posterior injury will fail if the ankle is simply dorsiflexed. (**b**) Grasping the heel and pulling it forward with ankle dorsiflexion will produce a congruent reduction

Fig. 24.6 (continued)

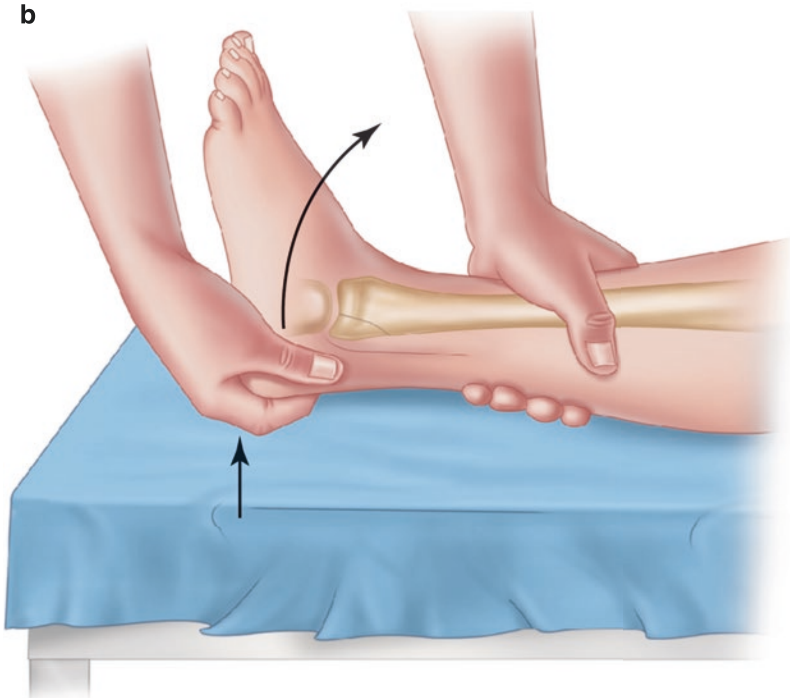

Fig. 24.7 Correction in the coronal plane is distal to the lateral malleolus and proximal to the medial malleolus

sary as intraoperative fluoroscopy or X-rays will probably be a luxury. With syndesmotic injuries, good exposure is required to assure reduction. Visual reduction of the fibula in the anatomic position while placing the syndesmotic screws with the talus dorsiflexed will assure no narrowing of the ankle mortise. Even with late presentation, displaced syndesmotic injuries can benefit from ORIF (Fig. 24.8). Removal of syndesmotic screws or ankle hardware, although elective, is frequently requested on a cultural basis, and adequate time for ligamentous and bony union should be allowed—3 and 6 months, respectively. But the patient should also be informed that if the syndesmotic screw is left in place, it will eventually break, without any further consequences (https://www2.aofoundation.org/wps/portal/surgery?showPage=diagnosis&bone=Tibia&segment=Malleoli).

The neglected, malunited, and late-presenting ankle fracture should also be considered for operative management if the above criteria are met. Lengthening of the fibula and osteotomy of the medial malleolus to realign the talus beneath the

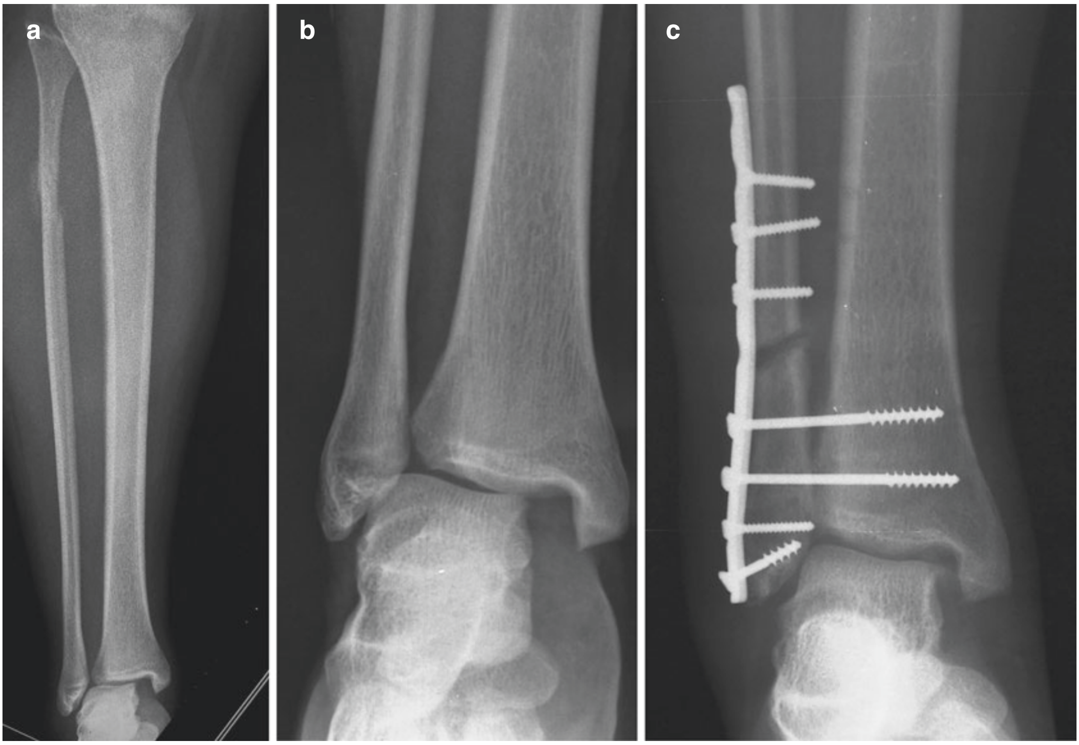

Fig. 24.8 (**a**) Residual syndesmotic widening at 6 weeks after a Maisonneuve-type injury. Note callus present at the proximal fibular fracture. (**b**) Close-up of mortise widening. (**c**) Postoperative appearance after fibular osteotomy and fixation with plate and two syndesmotic screws. The mortise has reduced to its normal width

weight-bearing axis of the tibia, even in the presence of some arthritis, can significantly decrease symptoms of malalignment and slow the progress of arthritis. Some residual anterior subluxation is functionally better tolerated than posterior subluxation, but both will accelerate the onset of post-traumatic arthritis. An ankle arthrodesis can salvage an arthritic malunion (see Chap. 41) (https://www.vumedi.com/video/ankle-fractures-management-of-malunited-ankle-fractures/).

Fractures and Fracture-Dislocations of the Foot

Although fractures and fracture-dislocations of the foot are common and range in severity and degree of displacement, the majority, as for ankle injuries, can be managed successfully by closed methods through skillful reduction and casting with the occasional need for percutaneous pins or external fixators to maintain satisfactory positions. The basic goal is a painless plantigrade foot. Some hindfoot valgus will unlock the transverse tarsal joints and achieve a more functional foot, while a stiff varus hindfoot or marked rocker bottom foot is poorly tolerated. Any cast should mold both the transverse and longitudinal arches. Earlier weight-bearing will lessen edema, stiffness, and osteopenia.

Fractures of the Talus

Non-displaced articular or non-articular talus fractures result from low-energy mechanisms and are amenable to cast management.

Talar neck fractures with associated disruption of the subtalar joint (Hawkins type 2) or neck fractures with disruption of both the subtalar and ankle joints (Hawkins type 3) are produced with more energy and have more soft tissue damage and higher AVN rates. They require adequate anesthesia to perform the appropriate plantarflexion maneuver to reduce the talar body at the subtalar and ankle joints. The midfoot-forefoot must be everted to disengage and reduce the fracture fragments from their usual varus position. A traction pin through the calcaneus to increase the joint space can help reduction. If unsuccessful, open reduction is worth the soft tissue risks; otherwise, the functional results are predictably poor. Peri-talar dislocations are relatively easy to reduce with adequate sedation and knee flexion. If instability remains postreduction (unusual), the addition of percutaneous pinning is warranted.

Fractures of the Calcaneus

Most fractures of the calcaneus are non-articular, non- or minimally displaced, and amenable to cast management. The exceptions are the joint depression type with significant varus position of the tuberosity or the “tongue type”, with or without skin compromise (Fig. 24.9). When there is significant widening of the hindfoot and the heel is in varus with significant loss of Bohler’s angle, adequate anesthesia is required to perform closed treatment that results in a more functional hindfoot position, i.e., regaining as much height as possible, narrowing the width, and improving alignment. The use of a traction pin, Schanz pin, or screw through the tuberosity as described by Essex-Lopresti can be utilized to correct and, in conjunction with a cast, maintain the position [3].

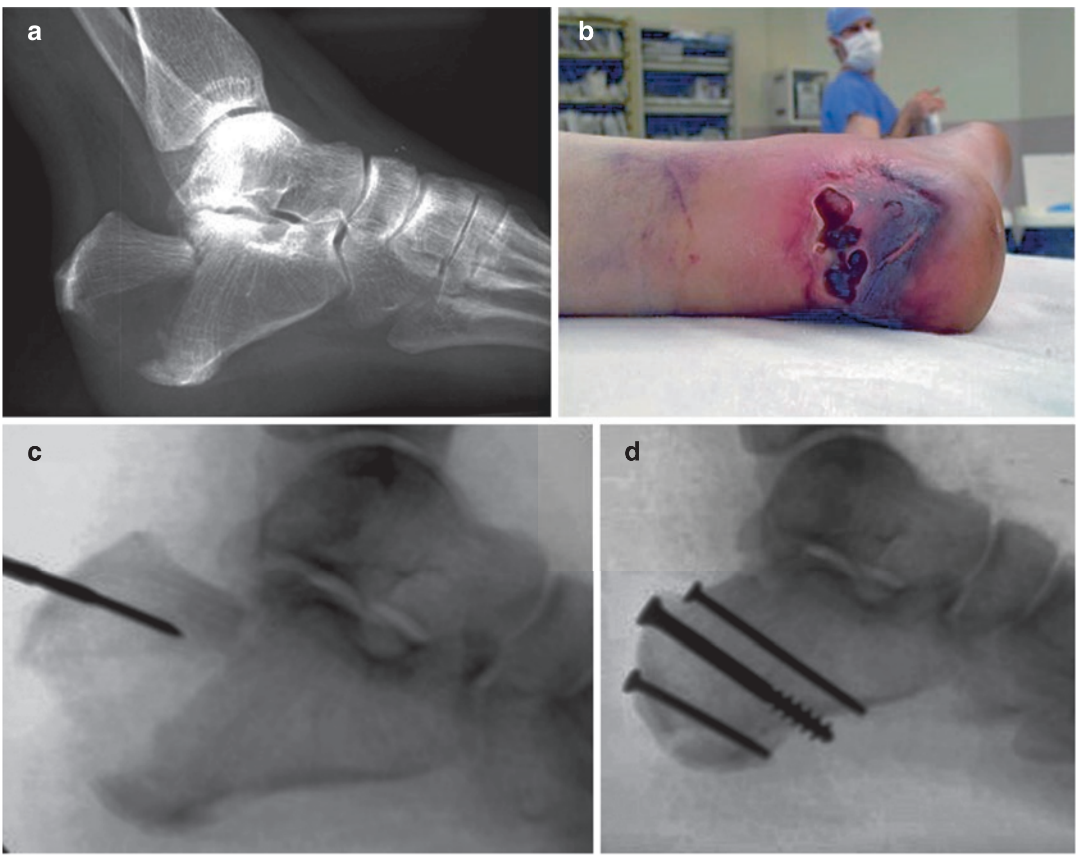

Fig. 24.9 (**a**) Typical displaced tongue-type fracture of the os calcis, with (**b**) ischemic changes of the overlying skin. (**c**) Reduction of the tongue fragment with a temporary Schanz screw performing an Essex-Lopresti maneuver. (**d**) Definitive fixation using percutaneous screws. (Courtesy of Stephen K. Benirschke)

The “tongue-type” fracture with the skin at risk is an urgent situation that should be splinted or casted in plantarflexion if palpably reducible or taken to the operating room for an Essex-Lopresti maneuver and pinning and casting. The cast should be changed from its plantarflexion position at 3–4 weeks to avoid Achilles shortening and disabling equinus contracture (Essex-Lopresti maneuver, https://pdfs.semanticscholar.org/ffaf/71f11ef8edabf8d61df8bb2559160b99c407.pdf).

Calcaneal fractures are probably best treated with casting and early weight-bearing to allow earlier return of function rather than protracted non-weight-bearing with or without a cast that will lead to disuse atrophy. Alternatively, an initial Jones dressing (large, bulky, moderately compressive dressing of thick cotton batting secured with elastic bandages), elevation, and active range of motion followed by a cast for weight-bearing comfort can be employed while avoiding prolonged non-weight-bearing (Lecture on calcaneal fx treatment, https://www.youtube.com/watch?v=wjtqNqg9eKA).

Midfoot Fractures and Fracture-Dislocations of Navicular, Cuboid, and Cuneiforms

These injuries frequently involve high to medium energy mechanisms of axial load or crushing forces. When significantly displaced or foreshortened, the use of finger traps with adequate sedation or anesthesia will help achieve acceptable reduction. Percutaneous pin fixation, pins and plaster, or external fixation are necessary for unstable fractures.

Lisfranc Fracture-Dislocations

These injuries come in various forms and degrees of ligamentous and bony disruption but should be amenable to closed reduction in the majority of cases with finger traps or tensioned K-wires through the metatarsals to apply traction, followed by percutaneous stabilization with crossed K-wires. Two to 3 months casting is adequate for the soft tissues to stabilize.

Metatarsal Fractures

The majority of metatarsal fractures will heal with or without treatment. Nevertheless, significant displacement and the resultant deformity can leave the patient with permanent disabling pain, and every effort should be made to provide adequate closed approximation of the fracture fragments. Finger traps or Kerlix looped between and around two toes are ideal for providing traction to gain length and alignment for the majority of these injuries. Wire traction pins through the phalanges and tensioned to a bar attached to a cast have creatively worked in the past with certain patterns. A situation with highly unstable and significant angulation that would alter the weight-bearing forefoot should be considered an indication to openly reduce and pin when the swelling has resolved (Fig. 24.10). Old injuries will likely need ORIF or bone resection.

Other Foot Injuries and Conditions

Mangled feet are clinically challenging to manage, as many places in the developing world find amputation culturally unacceptable, and the access to or availability of prosthetics may be limited. Thorough debridement—plus or minus pinning—while allowing the tissues to demarcate for later debridement or partial foot removal may be the most prudent approach.

Degloving injuries of the foot are common in populations that wear sandals or flip-flops. Distally based skin and soft tissue flaps often necrose, making coverage problematic (Fig. 24.11).

Charcot Fracture and Neuroarthropathy

With the epidemiologic transition occurring in many developing countries with increasing life

Fig. 24.10 (**a**) Fracture-dislocations of all metatarsophalangeal joints. (**b**) Postoperative X-ray showing result of retrograde pinning of all five rays

Fig. 24.11 (**a**) Superficial degloving injury of ankle and hindfoot. (**b**) Foot after debridement. (**c**) At time of STSG

expectancy and the emerging pandemic of obesity and type 2 diabetes, Charcot neuropathic fractures will present with increasing frequency. Total contact casting with limited padding except over the bony prominences and limited weight-bearing until the consolidation stages of the process are the mainstays of management. A plantigrade foot, without varus, will give the patient the best chance of avoiding the sequelae of insensate plantar ulcerations, infections, and amputation.

Achilles Tendon Rupture

The loss or weakening of the triceps surae function by Achilles tendon rupture or laceration can be especially debilitating to manual labor or farming livelihoods in the resource-poor settings. If presenting within the first month, the majority can be adequately managed through equinus casting, as surgical results are fairly equivalent [4]. If presenting late as a neglected Achilles rupture, a V–Y advancement should be considered to restore the essential function of this muscle group for normal gait, power, and strength.

Tips and Tricks for Management of Foot/Ankle Injuries in the Less-Resourced Environments

Closed, manipulative, functional, percutaneous, and less-invasive methods should all be considered the primary tools in the treatment armamentarium when managing lower leg, ankle, and foot injuries in less-resourced environments. They usually provide acceptable functional results with far less risk in the majority of cases while avoiding the significant and disastrous complications of wound healing, infections, or even loss of limb and life.

Rush Pin Techniques

Certain displaced distal tibial, malleolar, or even calcaneal fractures not able to be reduced and maintained in a cast may be addressed with the use of minimal incisions and Rush pins.

Simple (Poor Man's) External Fixation Technique

This technique can maintain a foot plantigrade to the tibia, especially in situations of significant soft tissue injury or burns. Steinmann pins are drilled retrograde through the first and fifth metatarsal metaphyses at a 45° angle exiting the foot dorsum to engage the distal tibia through small stab wounds while maintaining foot and ankle alignment [5] (Fig. 24.12).

Fig. 24.12 (**a**) "Poor man's" fixation when nothing else is available, using two Steinmann pins from first and fifth metatarsals to the anterior tibial crest. (**b**) Lateral view showing neutral position of the ankle joint

Percutaneous Steinmann Pins

Axial Steinmann pins can help maintain talar-tibial alignment, especially in the face of significant posterior malleolar comminution and instability. Manipulate the ankle to relocate the talus under the tibia as best as possible, and secure the reduction with a retrograde Steinmann pin drilled through the calcaneus, talus, and up in the tibial shaft; incorporate it in a below-knee non-weight-bearing cast; and remove the pin after 6–8 weeks. Or, for questionably compliant patients, use a long leg cast with 30° of knee flexion.

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Trauma of the Spine and Spinal Cord

25

Dheera Ananthakrishnan and Gilbert E. Cauilan

Introduction

The high health, social, and economic impact of spinal injuries is disproportionate in developing nations, as with all trauma, and a high index of suspicion for these injuries is key to assessment and treatment [1, 2]. Trauma protocols in the developed world have become highly sophisticated and include requisite CT scans of the cervical spine as well as the chest, abdomen, and pelvis. This is not possible in a resource-limited setting, but following the tenets of thorough examinations of the spine and the neurologic systems will alert the surgeon to these injuries with the potential for limiting disabilities [3].

Evaluation

Whether a trauma patient is examined in the OPD, ER, or ward, the system of evaluation should be the same. An initial neurologic exam should be performed looking first for gross deficits and then in more depth as allowed by the patient's clinical state. For example, a patient who has been thrown from a scooter is brought in by family for evaluation of a mangled leg. Observation alone should determine the gross motor function of the three other extremities.

In general, a thorough motor and sensory examination is necessary and should be recorded. It is mandatory to perform a rectal exam, assess the bulbocavernosus reflex, and document both of these. Perineal sensation needs to be assessed, looking for any sacral sparing. If a bulbocavernosus reflex is not yet present, the patient's spinal injury may still be evolving, and he is still in spinal shock. To improve outcomes, keep the patient's mean arterial pressure high to ensure perfusion of the spinal cord. This requires adequate monitoring (arterial line if possible) and will increase hemorrhage from other areas of trauma. As with all traumas, a multidisciplinary approach is the best for the patient, but in resource-challenged settings, the orthopedic surgeon may have to manage unfamiliar non-orthopedic issues.

High-dose steroids (methylprednisolone) in the immediate post-trauma period are no longer accepted as the standard of care in the developed world. The risks of increased incidence of infection and GI bleeding are high and the benefits minimal. Unfortunately, many surgeons worldwide are still using high-dose methylprednisolone protocols, and it is incumbent on visiting physicians to change such management.

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Once the bulbocavernosus reflex has returned, the examiner can be reasonably sure that any neurologic injury present is real and likely fixed. Any high-energy injury requires inspection and palpation of the spine by log rolling the patient and palpating the entire spine, from occiput to sacrum. Localized pain and tenderness, as well as ecchymoses, can direct the radiographic exam to be specific, which is imperative in any setting, but particularly in an austere one. Patients who are seen late should also be examined for pressure sores.

Injury to the content (the cord) is assessed clinically; injury to the container (the bone-soft tissue complex of the spine) is assessed radiographically. Lateral and AP cervical spine X-rays should be obtained if the patient is obtunded or if indicated from the initial evaluation. The C7–T1 level should be well visualized on the lateral film. It may be necessary to pull the arms caudally, while the X-ray is being taken for maximum visualization. If the cervicothoracic junction is still unable to be adequately assessed, a swimmer's view is required. If possible, the patient's neck should be immobilized with a cervical collar or taped across the forehead and secured to the backboard or bed during the clinical and radiographic evaluation. Sandbags on either side of the head as well as a support under the head can keep the head and cervical spine in neutral alignment. Log roll precautions should be used until the patient has been neurologically cleared.

Key Radiographic Points

- Cervical spine: visualize C7–T1.
- Cervical spine: evaluate continuity of the "three spinal lines," looking for incongruities at the anterior border of vertebral body, posterior border of the vertebral body, and junction of the laminae (Fig. 25.1).
- Thoracolumbar spine (AP view): look for vertebral height loss, widening of the pedicles, and increased distance between spinous processes when compared to those above and below (Fig. 25.2).

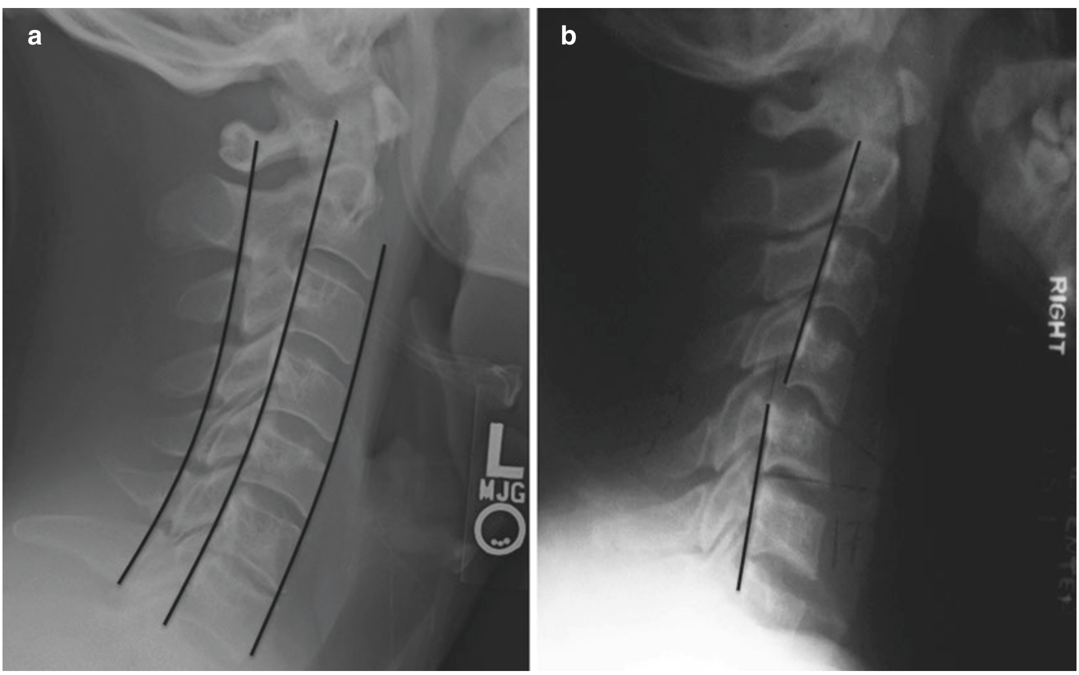

Fig. 25.1 (**a**) Normal lateral C-spine X-ray showing anterior spinal line, posterior spinal line, and spinolaminar line. (**b**) C-spine X-ray after trauma. Note break in posterior spinal line indicating C4–C5 facet disruption and bony instability

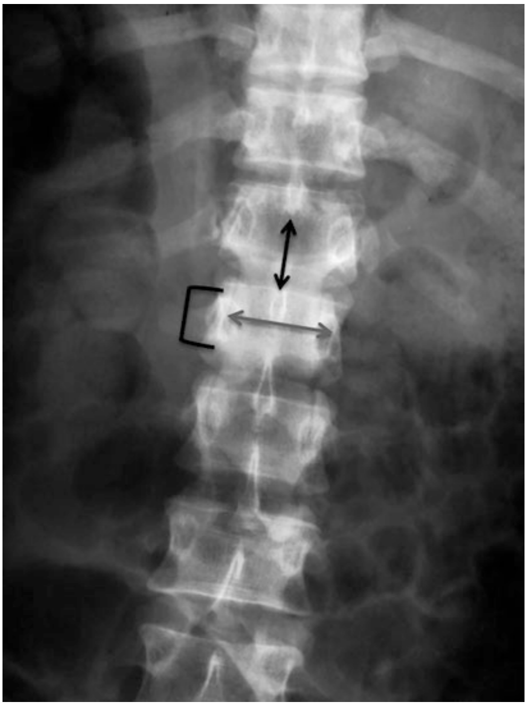

Fig. 25.2 AP X-ray of TL spine demonstrating key parameters. Interspinous distance (*vertical arrow*), interpedicular distance (*horizontal arrow*), and vertebral height (*bracket*)

Fig. 25.3 Lateral X-ray after T11–T12 trauma showing kyphosis and loss of vertebral body height and facet disruption (*circle*)

- Thoracolumbar spine (lateral view): look for vertebral body height loss and kyphosis; facet disruption is usually more evident on the lateral than the AP (Fig. 25.3).

Knowledge of the mechanism of injury enables further scrutiny of key areas and injury patterns:

- Axial load (Fig. 25.4): burst fractures with variable involvement of all three columns
- Flexion load (Fig. 25.5): anterior column compression with disruption of posterior column in tension
- Extension load (Fig. 25.6): anterior column tension failure with compression of posterior column

Instituting a protocol for evaluating these patients in the resource-poor setting is likely to be challenging, but the visiting orthopedist should make it a point to follow a consistent and thorough pattern of evaluation. At hospitals that see a fair amount of trauma, an initial evaluation of current processes is a good idea. This can be followed by an in-service for junior physicians, nurses, and radiology personnel on the implementation of a basic spine trauma screening protocol. Leaving the site with such a protocol for clinical and radiographic evaluation will go a long way toward both patient care and education.

Assessment of the Injury

Once an injury has been identified, the surgeon needs to assess its stability and, to a lesser degree, the acuity of the treatment needed. With regard to the second point, most of these patients will have had a significant delay between their injury and the time of evaluation, and it is unlikely that a

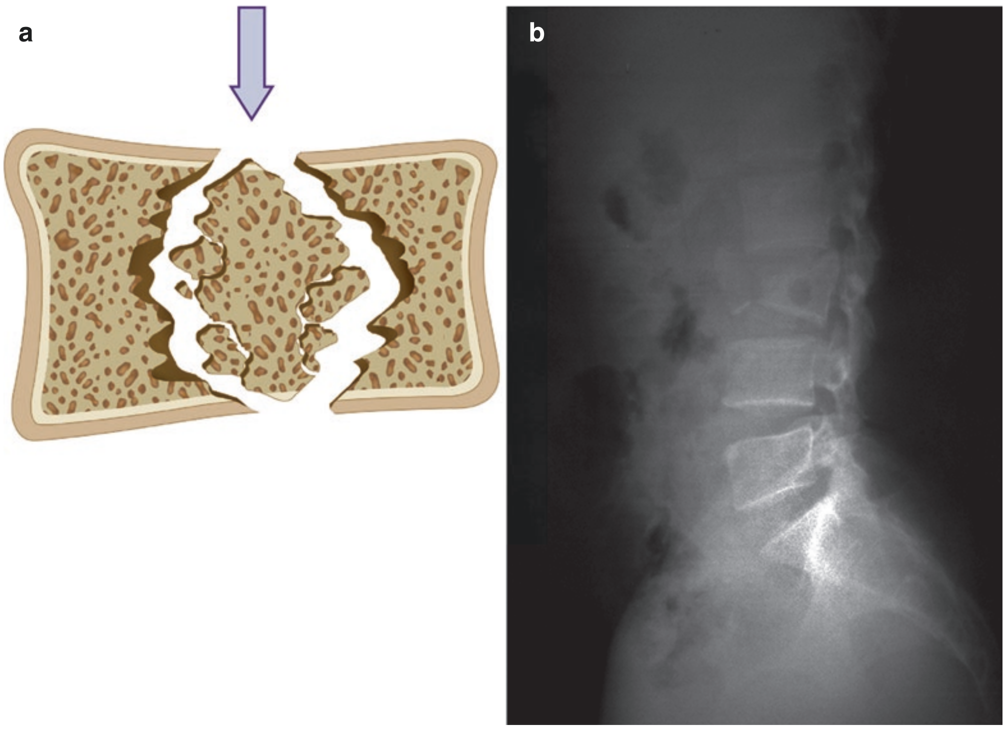

Fig. 25.4 (**a**) Axial load leads to compression or burst fracture. (**b**) Lateral X-ray of burst fracture of L3

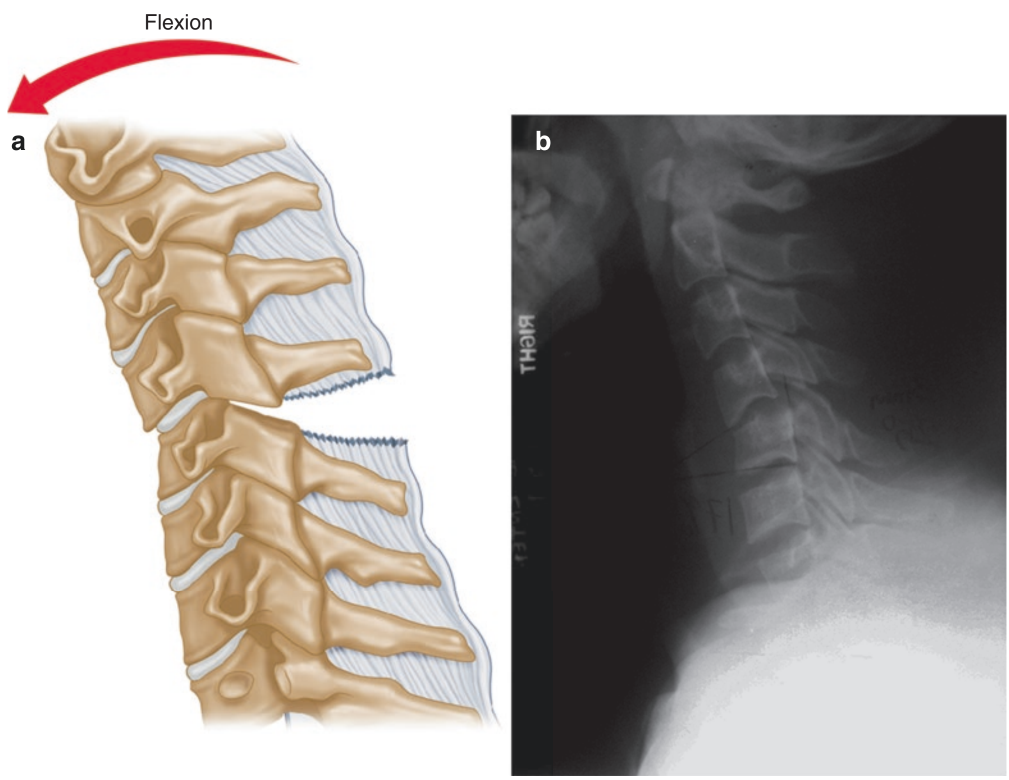

Fig. 25.5 (**a**) Flexion injury leads to compression injury of anterior elements and tension injury of posterior elements. (**b**) Lateral X-ray of flexion injury of C-spine

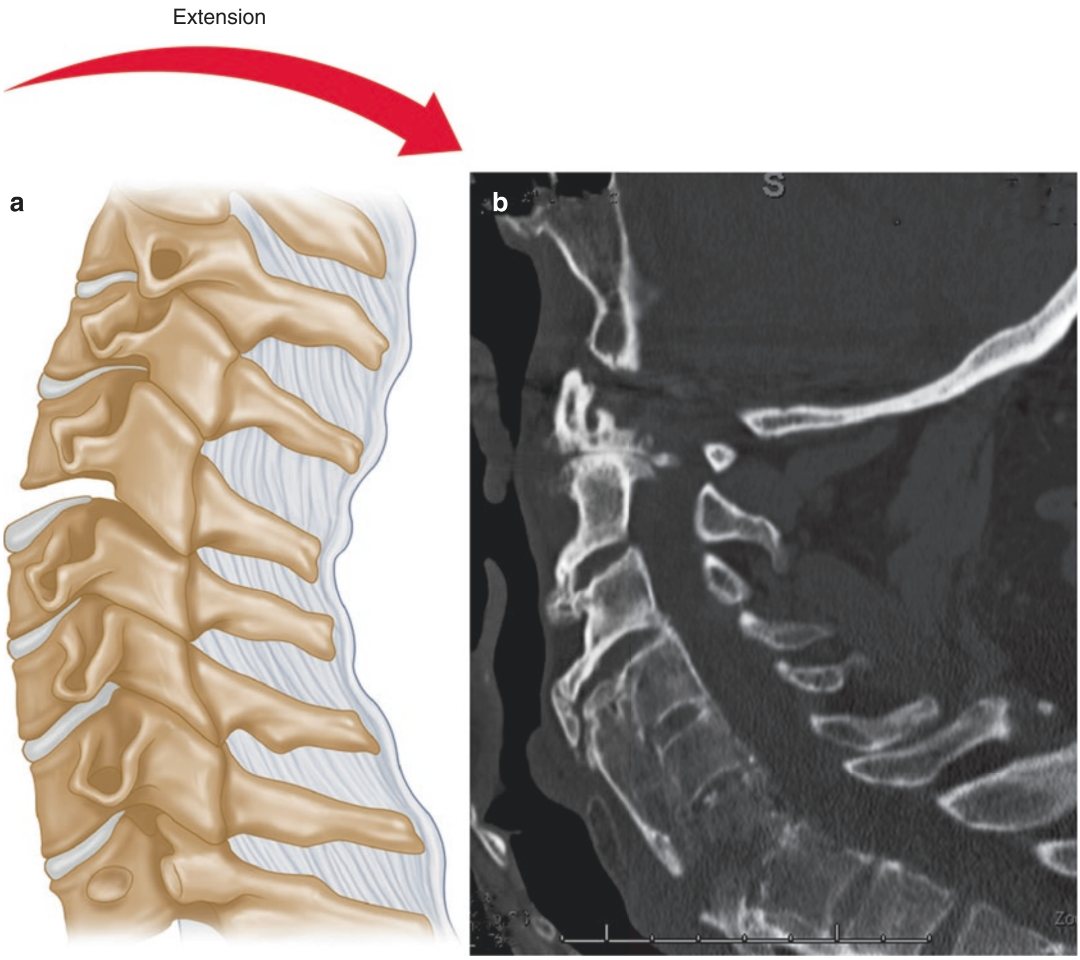

Fig. 25.6 (**a**) An extension load leads to anterior tension injury and posterior compression. (**b**) Lateral CT image of extension injury of C-spine

progressive neurologic deficit will present itself at a point at which an urgent decompression is necessary.

The issue of stability is of paramount importance when determining a treatment plan. Distinctions should be made between acute structural instability and the potential for late structural instability, as well as between neurologically stable and unstable lesions. An instability checklist to assist with treatment algorithms is shown below. At least three should be present for the injury to be considered unstable:

- Anterior elements not functional
- Posterior elements not functional
- Sagittal plane translation
- Sagittal plane rotation
- Positive stretch test (neural tension sign, radicular pain with elongation of nerve root)
- Spinal cord involvement

Stability

Although there is some controversy regarding classification of spinal injuries, the three-column concept is one that all visiting orthopedists should be able to apply when evaluating a spinal injury. The spine is divided into anterior, middle, and posterior columns (Fig. 25.7). Generally, an injury involving three columns is said to be acutely unstable, and in resource-rich environments these patients will often be treated surgically. The concept of acute versus late instability becomes an issue with two-column injuries. Often the indication for stabilization of these injuries is the potential for delayed-onset or late-onset deformity. A one-column injury is unlikely to need any type of stabilization, either with an orthosis, cast, or surgery.

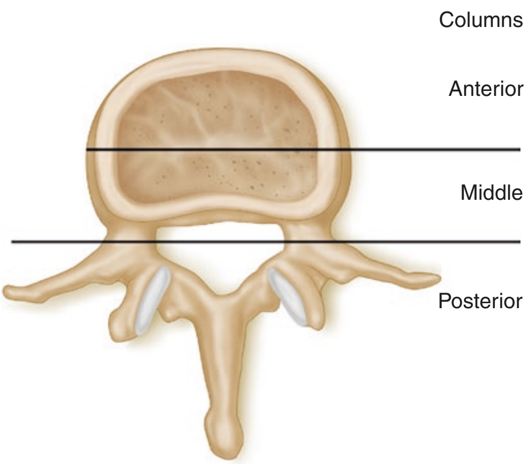

Fig. 25.7 The three columns of the spinal unit

A patient who is losing neurologic function is considered to be neurologically unstable. For the vast majority of neurologically unstable spine trauma patients in resource-poor settings, there is little to be done. Axial imaging with CT and MRI, if available, can give greater detail about the area in question, leading to consideration of a surgical decompression if the resources are available. Such expensive tests are helpful only if they will alter management.

Treatment

The most common injury patterns seen and their treatments in resource-poor settings are noted in the table below. If Gardner-Wells tongs are available for reduction of cervical fracture dislocations, the sterile pins should be placed at 60 lb inches of torque just above the external auditory meatus and below the equator of the skull (Fig. 25.8). Traction up to half of the patient's body weight is sometimes needed to achieve an awake reduction of

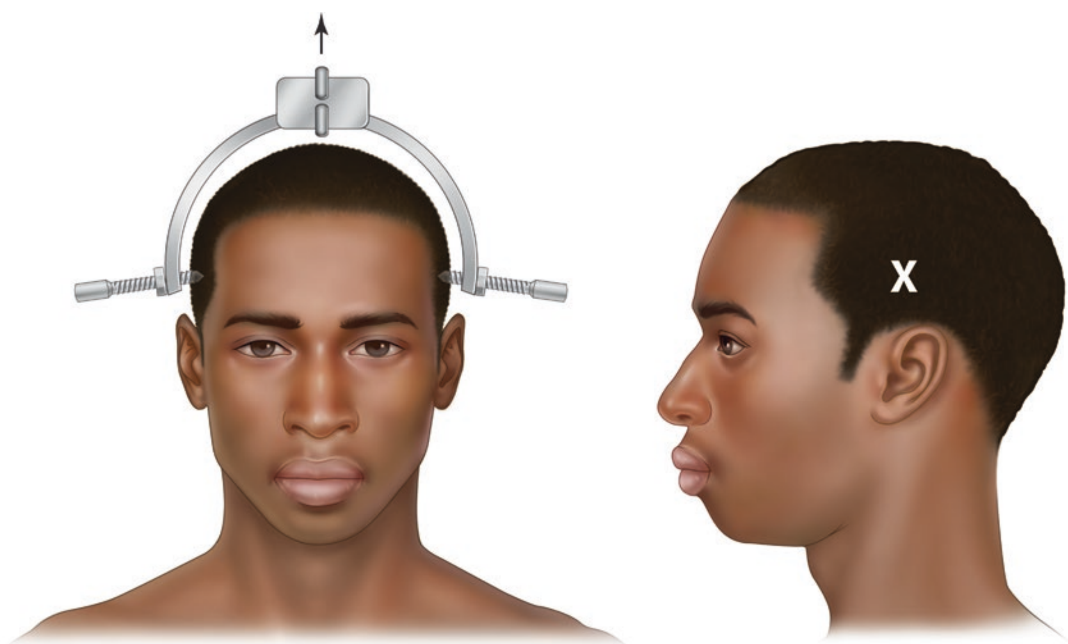

Fig. 25.8 Placement of Gardner-Wells tongs for reduction and traction of cervical spine injuries

Fig. 25.9 Head halter traction made from stockinette. Note that the patient is also wearing a neck collar

facet dislocations, which can be difficult for both the tongs and the patient to tolerate.

Alternatively, 10–20 lb of traction can be hung via stockinette head halter traction around the occiput and mandible (Fig. 25.9). This traction is less robust, and the patient may need to be in traction for 48–72 h to obtain a reduction.

Thoracolumbar fractures can be treated with log rolling at bed rest. Extension casting with delayed mobilization will usually give better results. However, it is difficult to place adults in an extension cast even in the developed world, as a special table and general anesthesia are usually needed (see Chap. 13).

In general, if instrumentation and a surgeon skilled in using it are not available, surgery is not advisable. Any non-instrumented decompression in a fracture setting is likely to fail, resulting in a late deformity and possibly worse neurologic function than that preoperatively. The one exception to this is an anterior cervical discectomy with iliac crest bone graft in a cervical fracture dislocation. In conjunction with a cervical collar, this can be an extremely effective treatment when performed by a trained surgeon.

Upper Cervical Injuries (Occiput to C2)

- Rarely seen due to high mortality rate and if seen are usually neurologically intact due to the large amount of space available for the spinal cord.
- Plain films with odontoid view, possible flexion/extension films.
- CT likely unnecessary, but helpful if available.
- Short period (3 weeks) of traction may be useful for C1–C2 injuries.
- Treatment in collar for C1–C2 injuries, halo may be used as well if available (Fig. 25.10).
- Surgery: not recommended in austere environments.

Lower Cervical Injuries

- Cervical fracture dislocations with facet subluxation or dislocation are common.
- Upright films, CT if possible.
- If no facet fracture, can attempt closed reduction with Gardner-Wells tongs (or halo) in an awake patient (follow neuro exam during reduction).
- Reduction will be difficult with a facet fracture present.
- Surgery: anterior or posterior reduction and fusion.
- NB: many of these injuries will be stable in a dislocated position. If the injury appears stable and the neurologic status is stable, it could be advisable to let the patient heal in a dislocated position.

Thoracolumbar Injuries

- Thoracolumbar burst fractures and compression fractures are most common.
- Upright films, CT if possible.
- Six to 12 weeks of bed rest with extension casting or TLSO for two- and three-column injuries.
- Late kyphosis can be a problem even with two-column injuries.
- Surgery: neurologic deficits may improve with a decompression, but this must be done in the setting of a fusion to prevent kyphosis, posterior fusion ± anterior fusion [4].

Fig. 25.10 (**a**) *Left*: lateral X-ray of C2 hangman's fracture with spondylolisthesis of C2 on C3. *Right*: acceptable reduction in halo vest. (**b**) Patient comfortable in halo

Pediatric Spine Trauma in the Resource-Poor Setting [5]

Eighty percent of spinal trauma in children occurs in the cervical spine:

- Four injury patterns occur: fracture, subluxation, fracture with subluxation, and SCIWORA (spinal cord injury without radiographic abnormality).
- Increased elasticity of ligamentous structures, incomplete ossification of the spinal column, and large head size with respect to body contribute to the high incidence of cervical trauma.
- Below the age of 8, injuries tend to be in the upper cervical spine. As the child ages, the fulcrum of the spine moves distally, and subaxial injuries are more common.
- Positioning the child on a backboard with pads under the torso should accommodate the relatively large head size.
- Radiographic evaluation is difficult due to the normal anatomy of pediatric spine, such as wedge-shaped vertebrae and pseudosubluxation of C2–C3 and C3–C4.
- Patients should be immobilized and evaluated with plain X-rays if unconscious and having high-energy injury, pain in the spine, focal tenderness, abnormal neurologic examination, transient neurologic dysfunction, obvious neck trauma (ecchymoses, skin compromise, swelling, deformity), and head/face trauma or an inconsolable child.
- Radiographs in general are extremely difficult to evaluate, and the surgeon should have a low tolerance for prolonged immobilization with a collar or bed rest and repeat examinations.
- SCIWORA tends to occur in younger children, due to the elasticity of the spine and the relative inelasticity of the spinal cord. The best course of action in a resource-limited setting is prolonged immobilization with a brace (up to 12 weeks) and reevaluation, weaning of orthosis. Flexion/extension radiographs may be helpful to pick up ligamentous instability.

Conclusion

Any spinal cord injury is a life-altering event. This is particularly true of patients in the developing world [6]. Even if the patient is at a hospital with the infrastructure, skills, knowledge, and material resources to provide modern surgical care for the unstable spine injury, the lack of rehabilitation can condemn the patient to a shortened life of dependence and infirmity [7]. When these patients are the breadwinners of the family, the impact of this injury is magnified exponentially. Any paralyzed patient at home becomes an extra mouth to feed and requires attendance for proper management, often taking a child away from school or from farm work.

Unless the orthopedic volunteer has extensive experience in spinal surgery and is working within a solid surgical and perioperative infrastructure, operative management of these injuries should not be undertaken. It can be easy for the visiting orthopedist to be anxious and discouraged when faced with a spine trauma injury; however, approaching these injuries in a methodical manner can allow for the best care possible in an unfortunate situation.

Low Back Pain in Austere Environments

Degenerative conditions of the lumbar spine are prevalent the world over. Orthopedic clinics in the developing world see many patients complaining of low back pain (LBP) and/or sciatica, and surgeons need to have some basic knowledge of diagnosis and treatment appropriate for the situation.

In the case of isolated LBP without lower extremity symptoms, 1–2 days of rest in the acute setting is reasonable. Acetaminophen and/or nonsteroidal anti-inflammatories can be helpful in treating acute cases. Except for recent trauma, most LBP is chronic or intermittent and nonspecific and part of the human condition. Treatment includes weight loss, evaluation of the environment that might be amenable to change, and core stretching and strengthening exercises, taught by the surgeon, nurse, or physical therapist (video of core exercises https://www.youtube.com/watch?v=vWdlivXrcbk). Discourage long-term anti-inflammatory and opioid use.

If there is concomitant buttock and/or leg pain, difficulty ambulating due to leg weakness, night pain, and bowel or bladder symptoms, this speaks for a possible neurologic issue. Spinal TB must be kept in mind, even in non-endemic areas (see Chap. 33 TB). A thorough back musculoskeletal and neurological exam is the first step. Patients with sciatica can still benefit from a course of exercise if they do not aggravate the symptoms.

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Part IV

Pediatric Trauma

26 General Principles of Pediatric Fracture Care

David A. Spiegel and Bibek Banskota

Introduction

While a fracture or dislocation in a child is often easily diagnosed with a simple clinical evaluation and a radiograph, a stepwise approach is useful to establish a diagnosis in cases that are not so obvious. This begins with a detailed history to establish the mechanism of injury and the amount of energy sustained. If the patient cannot identify the time of injury, then symptoms may relate to repetitive trauma or to another diagnosis such as infection or neoplasia in which case the pain may be dull, continuous, gradually increasing, and worse at night. Before examining a child, ask him to show you the area of maximal tenderness with the tip of an index finger. It is often challenging to examine a child who is apprehensive and in pain, so the physical exam must be gentle and non-threatening. It is useful to ask a parent to assist you, by talking them through parts of the examination. Establish the practice of never looking at radiographs before speaking with and examining a patient. Given the various stages of ossification of the skeleton, there are often irregularities seen that could represent a non-displaced fracture in the appropriate clinical circumstances. Remember that some fractures will not appear on a radiograph for 10–14 days, so if the diagnosis is unclear, it is useful to splint or cast the affected area for 10–14 days, after which the immobilization is removed and the clinical exam and radiograph repeated.

Although detailed information on the national, regional, or local prevalence of non-accidental injury or child abuse may not be accessible, clinicians should always have an index of suspicion, especially in younger children and infants when there is no history of trauma or the history is inconsistent with the fracture pattern. Heightened concern might be indicated, for example, in a femur fracture diagnosed before the patient is ambulatory. A detailed history of the injury is important, as well as a comprehensive examination of the child to identify any skin bruising or abrasions, other sites of tenderness, or evidence of injuries to other systems. A skeletal survey is useful to rule out other fractures or fractures in different stages of healing. The differential diagnosis includes conditions such as osteogenesis imperfecta or other diagnoses associated with an increased risk of fractures. Under ideal circumstances, a team of

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health professionals works together to evaluate cases suspected of having non-accidental injury.

The majority of fractures and dislocations in the pediatric population can be managed non-operatively, recognizing that closed management often requires greater time and resources. To achieve adequate results, the surgeon must have an understanding of the fracture's remodeling potential, an appreciation for the mechanism of injury, meticulous casting technique, and close follow-up during early healing to correct minor incongruities and deformities (Fig. 26.1) (see

Fig. 26.1 (**a**, **b**) This forearm fracture was treated by a locally made splint. (**c**) In a similar case, the fracture healed in excellent alignment; (**d**) however, the treatment was complicated by compartment syndrome and a Volkmann's ischemic contracture. (**e**) Gangrene can complicate casting

Chap. 13). While image intensification has revolutionized children's fracture care by facilitating minimally invasive techniques for reduction and fixation, such technology is often unavailable in resource-challenged environments.

The most common anesthetic technique for reduction is the hematoma block, performed using the *barbotage* technique. Approximately half the local anesthetic is injected into the fracture, and the hematoma is aspirated to restore the initial fluid volume within the syringe. This process is repeated several times to distribute the anesthetic. After the final aspiration, the volume of the hematoma should be unchanged. Ketamine is also useful when available.

A subset of fractures—displaced intra-articular, irreducible fractures and unstable fractures—require open surgical treatment and/or fixation to achieve the best results, recognizing that open approaches increase the risk of infection (Fig. 26.2). A prompt diagnosis and early referral are essential if the resources and expertise are unavailable locally. Fracture fixation can usually be done with Kirschner wires or Steinmann pins. Without an image intensifier, "blind pinning" may be considered in selected cases, after which alignment and pin placement are assessed with radiographs, although an open reduction is often more appropriate. Open reduction via small incisions can facilitate minimally invasive fixation techniques such as intramedullary nailing of diaphyseal fractures.

Fracture Healing and Remodeling

The inflammatory stage of fracture healing begins immediately after the injury and involves hematoma formation around the fracture ends. In the second or reparative phase, random bone is laid down by the endosteum (endochondral) and the periosteum (intramembranous). The last

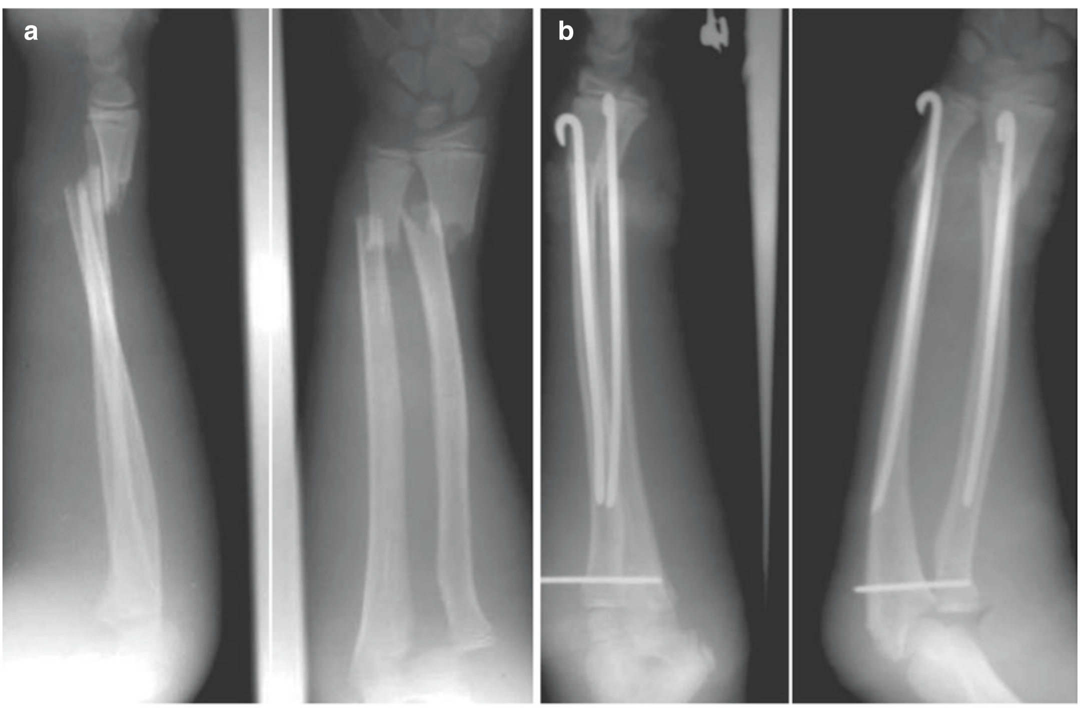

Fig. 26.2 (**a**) X-rays of a distal radius and ulna fracture with dislocation of proximal radius (Monteggia variant) was (**b**) initially treated by open reduction and nailing. The patient developed an infection which was (**c**) treated by irrigation and debridement followed by plating. This was complicated by extensive osteomyelitis, a difficult problem to solve

Fig. 26.2 (continued)

stage of healing involves remodeling, the extent of which is determined by (1) skeletal age, (2) the specific bone involved, (3) fracture location within the bone, (4) distance of the fracture from a joint, and (5) whether the angulation occurs in the plane of motion of the neighboring joint.

The remodeling potential is greater when more than 2 years of growth remain and is especially good in children less than 8–10 years of age and in metaphyseal fractures and when the angulation is in the plane of motion of the joint. Seventy-five percent of remodeling occurs from asymmetric physeal growth, while 25% is due to a combination of appositional bone growth on the concavity and resorption of bone on the convexity. General guidelines for acceptable alignment are illustrated in Table 26.1.

Box 26.1 Bone Age Differences

In sub-Saharan Africa, it is common to find patients in their late teens or early 20s with epiphyseal fractures. From a study from Malawi, in 85.6% of 119 patients, the skeletal ages trailed chronological ages by a mean of 20 months [1]. Anthropological studies from the 1950s showed similar results when comparing East and West African populations to the Western middle class subjects of the commonly used bone atlases. Whether similar differences exist in other populations is unknown.

Physical anthropologists and forensic experts agree that the variations in the rates and times of human maturity are multifactorial and include genetic and environmental factors. Nutrition contributes to growth and developmental potential, and poor nutrition is commonly associated with stunted growth and delayed development. Chronic low dietary intake usually presents as a slow growth during childhood and adolescence, a late adolescent growth spurt, and a prolonged period of growth [2]. The specific effects of prenatal nutrition and the roles of caloric vs. protein malnutrition are not well understood.

Environmental stress also influences physiological age, but how this occurs is controversial. Chronic diseases may have a role on their own or by the accompanying malnutrition, especially in the young. All of these factors may affect growth through alterations in the immune system.

Genetic factors affecting skeletal maturation are sure to play a role, as populations differ in average skeletal size, degree of sexual dimorphism, and proportions, while the variations within a population can be great.

Not all patients presenting in their late teens or early 20s with epiphyseal fractures are short or classically malnourished in appearance. The main points for the orthopedic surgeon are to be aware that physeal fractures occur in this older age group and to take care in planning any procedures dependent on remaining bone growth or giving medical legal statements about age. This latter can be problematic as birth certificates are often lacking and knowledge of date of birth vague. At the same time, having an extended growth potential to remodel a fracture can be an advantage.

Table 26.1 General guidelines for acceptable alignment of fractures in children and adolescents

General guidelines for acceptable alignment of common children's fractures				
Lower extremity				
Femoral shaft	Age (years)	Varus/valgus (°)	Anterior/post-angulation (°)	Shortening (mm)
	Birth–2	30	30	15
	2–5	15	20	20
	6–10	10	15	15
	>11	5	10	10
Tibia and fibular shaft			≤8 years	>8 years
	Valgus		≤5°	≤5°
	Varus		≤10°	≤5°
	Anterior angulation		≤10°	≤5°
	Posterior angulation		≤5°	0°
	Shortening		10 mm	5 mm
	Rotation		≤5°	≤5°

Adapted from Beaty and Kasser [3]

Physeal Injuries

Physeal injuries can be due to fractures, infections (osteomyelitis or septic arthritis), tumors, irradiation, vascular insults, and other injuries (thermal, electrical). Physeal fractures are usually classified according to Salter-Harris Classification (Fig. 26.3a). Peterson has added two additional types, (1) a metaphyseal fracture which extends into the physis (Fig. 26.3b) and (2) a partial loss of the physis, for example, medial malleolar loss from a lawn mower injury. The most common complication of physeal injuries is growth disturbance, which results in an angular deformity and/or limb length discrepancy. Growth disturbance is associated with partial or complete physeal arrest or physeal growth deceleration without full arrest.

The consequences of physeal injuries are more profound for younger children with considerable growth remaining, high-energy injuries, and in selected physes such as the distal femur, due to its large surface area and undulations. The risk of iatrogenic injury can be reduced by treatment within 7 days after injury, gentle manipulation, and avoiding multiple or repeat reductions.

In the absence of advanced imaging, the diagnosis of growth arrest must be made on plain

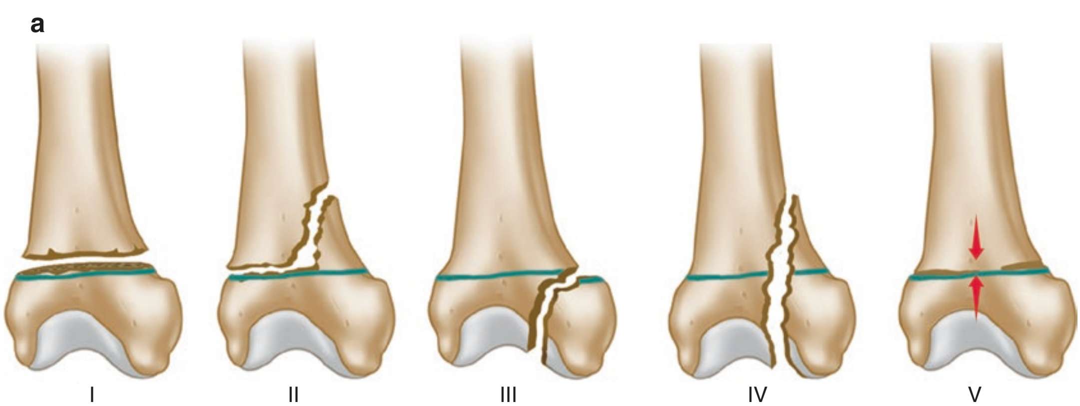

Fig. 26.3 (**a**) Salter-Harris classification of fractures. Type *I* fractures extend through the physis, while the Type II patterns travel through the physis and then exit through the metaphysis, leaving a metaphyseal component termed the "Thurston-Holland" fragment. Type III fractures extend through the physis and then exit the epiphysis, creating displacement at both the physis and the joint surface. Type IV fractures extend from the metaphysis, across the physis and epiphysis, exiting in the joint. The rare Type V fracture is a compression injury that is not readily diagnosed on initial injury films but presents later with growth disturbance. (**b**) A metaphyseal fracture extending into the physis

Fig. 26.3 (continued)

radiographs, and findings include the loss of the normal physeal contour and asymmetric Harris growth arrest lines (Fig. 26.4). While it may be impractical to provide long-term follow-up for most patients with physeal fractures, that subset of injuries with the highest risk—Salter-Harris III and IV, high-energy mechanism, late manipulation, or reduction—should be followed closely. It is critical to educate patients and their families about the possibility of growth disturbance, by indicating the possible clinical features, such as development of an angular deformity and the time over which such changes might occur. For example, rapidly growing physes such as the distal femur might show a disturbance within 2–4 months, while a slower-growing physis such as the distal tibia might not show clinical signs until a year or more after the injury. While routine radiographic follow-up within the first few months might identify a growth disturbance before a clinical deformity has occurred, it remains a challenge for many patients to return to a health facility for follow-up. The best option may be to teach families how to evaluate limb lengths and symmetry. Community-based rehabilitation workers can be taught to identify complications at an early stage.

If a physeal fracture is malaligned and healing has progressed beyond 7–10 days, several options exist. If the degree of malalignment is within the expected remodeling potential of that physis and the patient is asymptomatic, observation is the best choice. When alignment is beyond the limits of remodeling and/or the patient's function is compromised, consider an open realignment and stabilization, recognizing and accepting that a physeal arrest will likely occur. Future plans for maintaining limb lengths within an acceptable range must then be discussed.

The predicted discrepancies after complete physeal arrest are based on the growth potential of the individual physis and the number of years of growth remaining. If a complete growth arrest is diagnosed, an epiphysiodesis of the contralateral physes may prevent a limb length discrepancy from developing. In younger children, the degree of anticipated discrepancy or the loss of adult height associated with contralateral epiphysiodesis may be unacceptable to the family, and limb lengthening may be the only alternative. For partial growth arrest, both progressive angular deformity and limb length inequality have to be managed, and a number of reconstructive options can be considered. Estimates for the absolute growth in millimeters and percentage growth of each physis have been gathered from the most recent edition of Rockwood and Wilkins' Fractures in Children and are shown in Table 26.2.

Management of Neglected Fractures and Dislocations

Fractures and dislocations presenting weeks to months following injury are common and challenging. Treatment decisions are based on symptoms and their impact on the patient's activities of daily living, the local resources, and the availability of rehabilitation. Outcomes following treatment of neglected fractures and dislocations are often inferior to those for the same injuries presenting acutely, especially when intra-articular

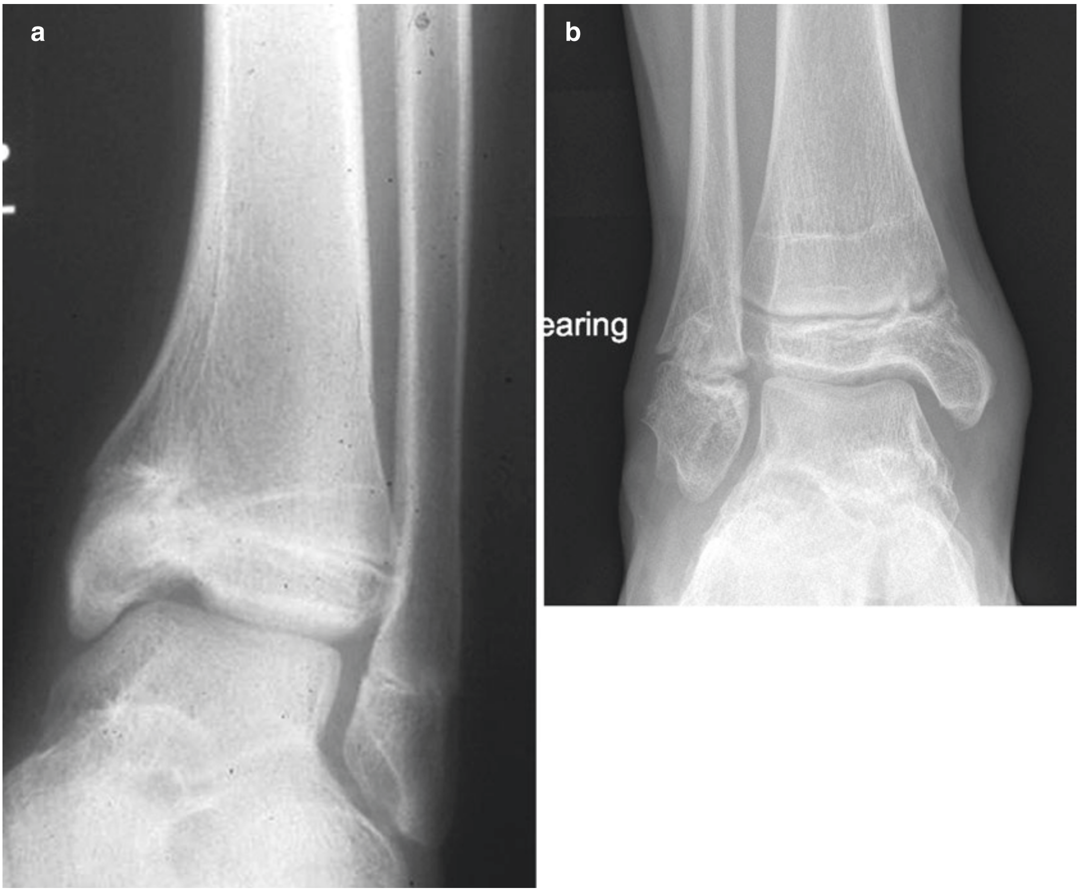

Fig. 26.4 (**a**) A healed physeal fracture of the medial malleolus with an ankle varus deformity. Note the asymmetric growth arrest line. (**b**) Symmetric growth arrest lines suggest resumption of normal growth

Table 26.2 Estimated growth of individual physes as a percentage within each bone and also in millimeters per year

Physis	Estimated % of growth	Estimated growth (mm/year)
Proximal humerus	80	7
Distal humerus	20	2
Proximal radius	25	1.8
Distal radius	75	5
Proximal ulna	80	5
Distal ulna	20	1.5
Proximal femur	30	3.5
Distal femur	70	9
Proximal tibia	55	6
Distal tibia	45	3–5
Proximal fibula	60	6.5
Distal fibula	40	4.5

From Rathjen and Birch [4]

and/or physeal. However, using appropriate principles, improvements in symptoms and/or function can be expected in most patients.

Fractures with symptomatic malalignment after complete healing require an osteotomy. When fractures present up to 3–4 weeks post-injury, but prior to complete union, osteoclasis can “loosen up” the fracture and facilitate realignment. Osteoclasis can be performed by closed manipulation, by percutaneous drilling, or by open techniques. Angulation is easier to correct than shortening. Either skeletal traction or an external fixator can gradually restore length and alignment after osteoclasis. An alternative is to perform an open, acute shortening and realignment.

Neglected intra-articular fractures and joint dislocations are more difficult to manage, especially in weight-bearing joints, and often require salvage strategies such as intra-articular osteotomy and arthrodesis. While much of the available information in the literature focuses on adults, the same principles can be adapted to children and adolescents, taking into account the potential for remodeling and growth (see Chap. 41).

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Management of Upper Extremity Fractures

27

David A. Spiegel and Bibek Banskota

Proximal Humerus

The majority of proximal humerus fractures, including those with considerable angulation, can be managed non-operatively with a simple sling or collar and cuff as long as 2 years of growth remain (Fig. 27.1).

Supracondylar Humerus

Supracondylar humerus fractures, especially those with complete displacement, are a challenge in any setting. No remodeling of coronal angulation—varus or valgus—can be expected. However some remodeling of sagittal plane angulation will occur as the deformity lies in the plane of elbow motion. Non-angulated translation in either the coronal or sagittal plane will typically remodel. Cubitus varus, with or without hyperextension, is the most common deformity and is largely cosmetic, seldom interfering with function.

Non-displaced fractures, *Type I*, can be treated by a posterior splint or a long arm cast for 3 weeks, after which a removable splint or sling protects the elbow for several additional weeks.

Type II fractures have apex anterior angulation with an intact posterior cortex and greenstick deformation but no displacement. They should be reduced so that on a lateral x-ray, the anterior humeral line falls through the center of the capitellar ossification center (Fig. 27.2). The reduction is easily achieved by fully flexing the elbow. If hyperflexion is required to achieve the reduction, once the bone ends are interdigitated, immobilization at 90° will usually hold the reduction without need for continued hyperflexion. The fracture can be stabilized by percutaneous pinning or managed in a cast with close follow-up as it is stable in rotation due to the intact posterior hinge.

The goal of treating completely displaced supracondylar fractures, *Type III*, is to obtain an adequate functional result while avoiding complications. Ninety-five percent of Type III fractures are extension type (Fig. 27.3). The 5% flexion-type injuries are recognized by flexion of the distal fragment (Fig. 27.4) often with severe rotational deformity, seen by differing orientations of the two fragments on one x-ray. Flexion-

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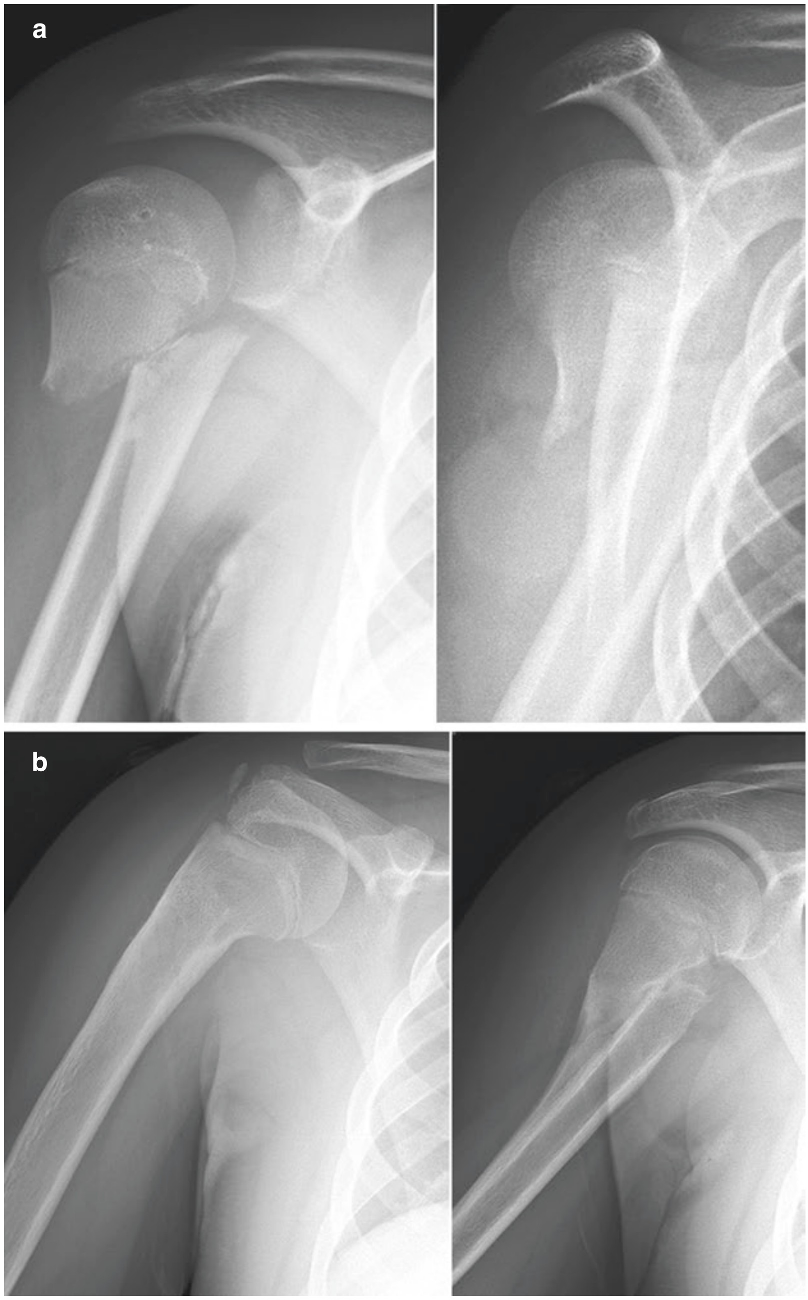

Fig. 27.1 (**a**, **b**) This 11-year-old female was (**a**) treated in a sling and (**b**) after 8 weeks demonstrated early remodeling with a full range of motion

type fractures are typically globally unstable, have no distinct periosteal hinge to assist in the reduction, and often require open reduction.

Type III fractures are unstable and if not pinned must be held in hyperflexion after reduction. This position increases the risk of vascular complications and is not recommended. If an image intensifier is available, closed reduction and percutaneous pinning can be attempted up to 5–7 days post-injury. Reduction involves applying gentle traction with the elbow in mild flexion while correcting any varus or valgus deformity. The elbow is gently and progressively flexed while applying pressure from posterior to anterior on the distal fragment and simultaneously pushing the proximal fragment of the humeral

Fig. 27.2 Type II supracondylar humerus fracture with mild extension. Note the anterior humeral line falls anterior to the capitellar ossification center

Fig. 27.3 Type III fractures are displaced and have no cortical continuity

shaft from anterior to posterior. Extension fractures usually have an intact periosteal hinge posteriorly, and the reduction is locked by fully flexing the elbow. Care must be taken to ensure that the distal fragment is properly aligned with the proximal prior to fully flexing the elbow, or the periosteal hinge may be torn creating global

Fig. 27.4 Flexion-type supracondylar humerus fracture. Note the anterior humeral line falls posterior to the capitellum

instability. Three divergent laterally placed bicortical K-wires are sufficient fixation (Fig. 27.5).

With medial comminution or impaction, a medial K-wire can help prevent collapse into varus. It is inserted via a small incision over the medial epicondyle to avoid injury to the ulnar nerve. After placing the medial pin, flex the elbow to ensure that the ulnar nerve does not subluxate anteriorly creating impingement, as a subset of the population has positional ulnar subluxation. The extremity is placed in a posterior splint with the elbow in 60–70° flexion and the patient observed for 24 h for swelling and neurovascular function.

In some cases of Type III extension fractures, the proximal fragment is impaled through the brachialis muscle with the tip palpable under the skin. Often these show extensive bruising over the antecubital fossa (Fig. 27.6). A “milking maneuver” of the soft tissues should dislodge the fragment prior to reduction.

Flexion pattern fractures are best pinned. If an image intensifier is available, a hand table is suggested when reducing and stabilizing these unstable fractures. The fracture is first reduced in the coronal plane. With the image intensifier rotated to show a lateral projection, the elbow is

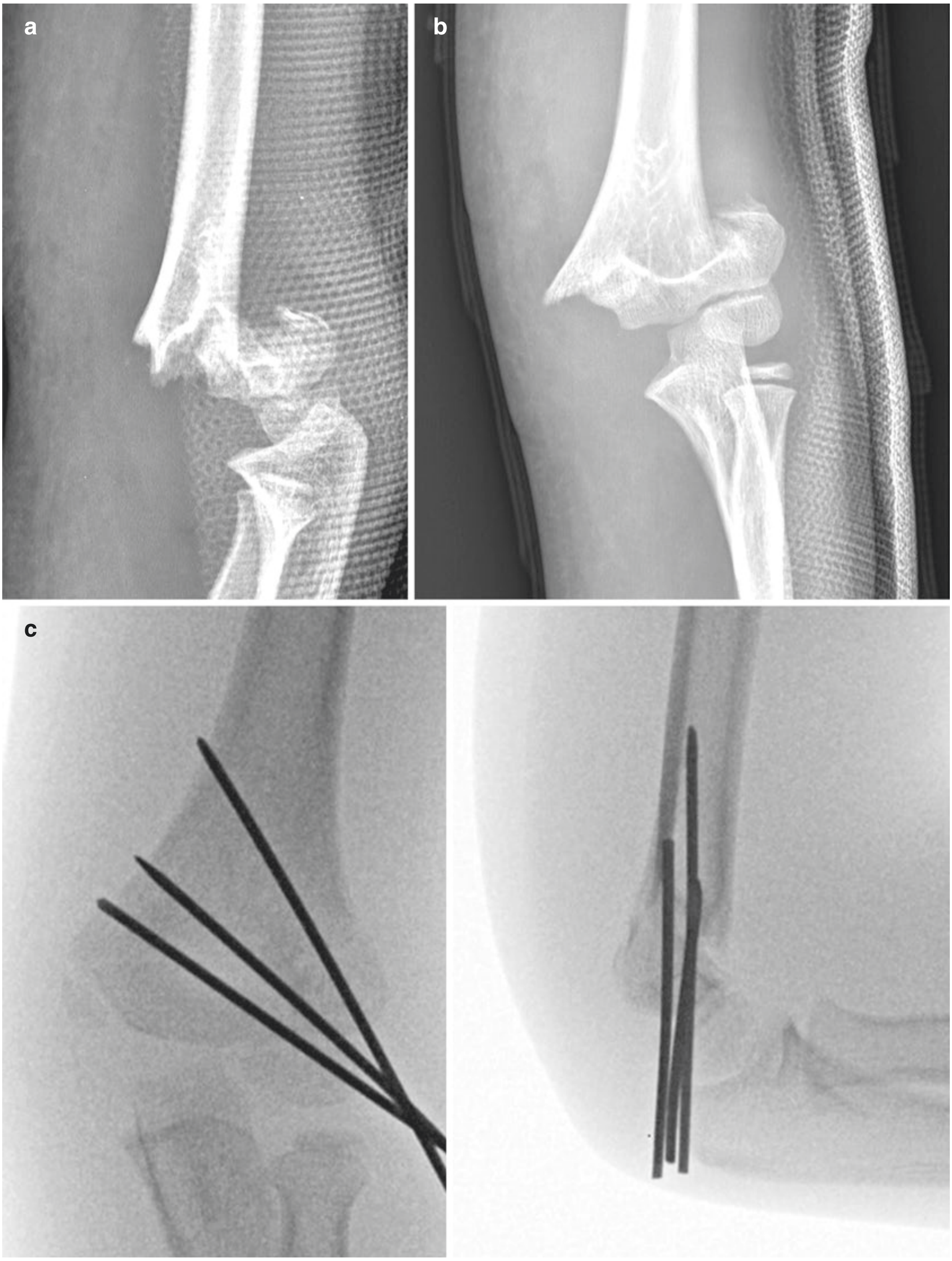

Fig. 27.5 (**a**, **b**) Displaced fractures are treated by open reduction and pinning or (**c**) percutaneous fixation

Fig. 27.6 Ecchymosis over the distal and medial aspect of the upper arm is common when the proximal fragment pierces the brachialis

extended to reduce the sagittal malalignment. In fractures that need considerable extension, one or two pins can be placed up to the fracture before extension and only advanced across the fracture after extending the elbow.

Reduction for either extension or flexion Type III injuries can be facilitated in selected cases by percutaneously introducing the blunt end of a Steinmann pin from a posterior approach and using it as a "shoehorn" to reduce the fracture (Fig. 27.7).

Options for the management of acute displaced fractures, especially in the absence of an image intensifier, include traction, closed reduction and "blind pinning," or open reduction with percutaneous pinning. Dunlop's side arm traction or olecranon traction can be used as a temporary measure in cases of severe swelling or as the definitive treatment (Fig. 27.8). After 2–3 weeks

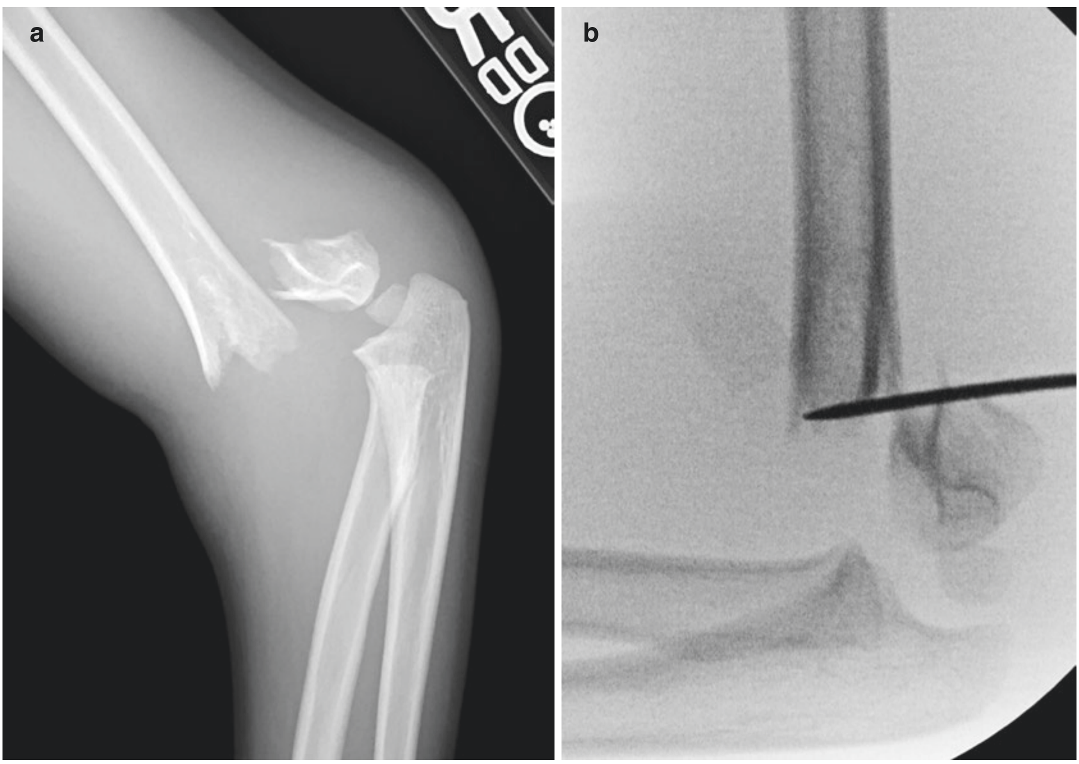

Fig. 27.7 (**a**–**c**). (**a**) Lateral x-ray of a widely displaced Type III supracondylar fracture that proved difficult to reduce. (**b**) Under C-arm control the blunt end of a Steinmann pin was inserted posteriorly into the fracture as a joystick to lever the fragments into alignment (**c**)

Fig. 27.7 (continued)

and callus has formed, the traction is converted to a splint or cast.

Nerve injuries are seen in up to 20% of patients with displaced supracondylar humerus fractures. The most commonly injured nerve is the anterior interosseous branch of the median nerve, tested by asking the patient to make a circle between the tips of the thumb and the index finger—an "OK" sign—that requires flexion at the two distal phalangeal joints. Radial nerve function is assessed by extending the interphalangeal joint of the thumb, and the ulnar nerve is tested by crossing the index and middle fingers.

When a nerve injury is identified at the time of presentation, the fracture is reduced and stabilized by closed or open means. In most cases the nerve will recover fully. If the fracture cannot be adequately reduced, an open exploration is suggested as the nerve or soft tissues may be trapped in the fracture. When a nerve palsy is diagnosed *after* the fracture is reduced in a closed manner and stabilized, nerve exploration should be considered, especially if an anatomic reduction was not achieved. A median nerve palsy may mask the pain associated with an evolving compartment syndrome.

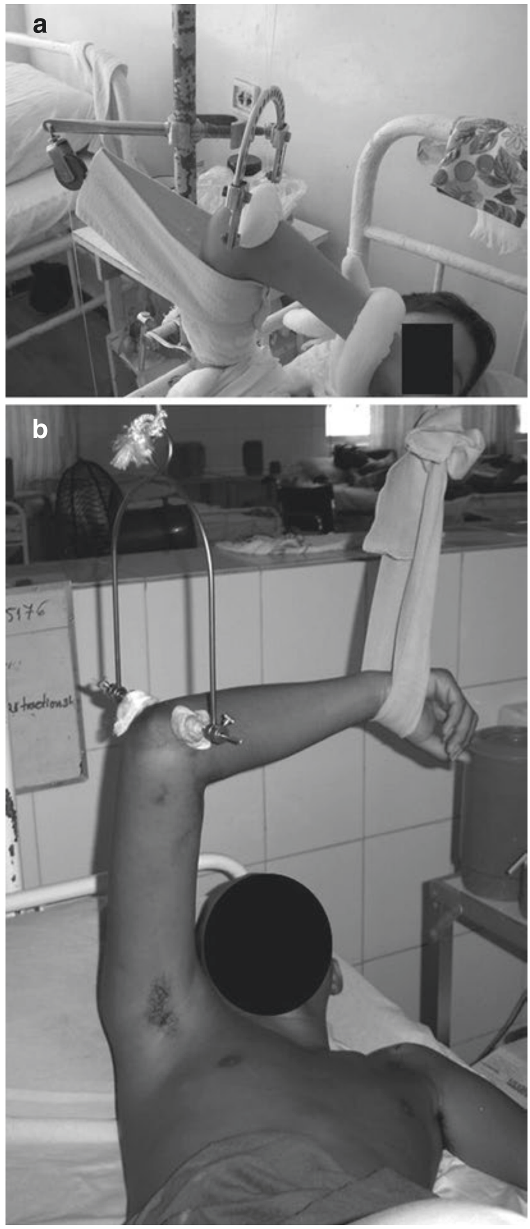

Fig. 27.8 (**a**) Skeletal traction is an excellent option for supracondylar fractures when an image intensifier is not available. (**b**) Several traction variations can be used. (**a** Courtesy of Jonathan Phillips, M.D.)

Vascular injuries occur in approximately 5% of cases. Patients presenting with inadequate tissue perfusion—typically a pulseless and pale hand—are treated by urgent reduction of the fracture. If adequate pulse and perfusion are restored, the limb is splinted in 60–70° flexion at the elbow, and the patient is observed for 24–48 h. Exploration is required if adequate perfusion is not restored. The vessel may be entrapped within the fracture site especially if an anatomic reduction is not achieved, but more commonly the vessel is tethered to bone.

The management of the pulseless but well-perfused extremity—the pink pulseless hand—after reduction remains controversial, as there is no clear definition of "well perfused." The vessel is often in spasm and the pulse will return with time, sometimes days later. Sometimes the patient may be relatively hypotensive while under anesthesia, and it may be reasonable to reevaluate the perfusion and pulse once the patient's blood pressure has been restored to the normal range while waking up from anesthesia. If the pulse does not return and the perfusion is deemed adequate, many surgeons advocate close observation with frequent neurovascular checks. While the indications for immediate exploration are debated, a strong case can be made for exploration in patients with an absent Doppler and/or coexisting median nerve palsy. Pulse oximetry may assist with monitoring during the postoperative period, but this device measures skin oxygenation and not muscle perfusion, making the clinical examination of muscle function essential, especially in the diagnosis of a coexisting compartment syndrome.

Indications for an open reduction include inadequate tissue perfusion, the inability to achieve a satisfactory closed reduction, or when no image intensifier is available. An anterior approach affords direct exposure of neurovascular structures. The posterior approach may increase the risk of stiffness and triceps weakness and give no access to neurovascular structures. A medial approach is most appropriate when the proximal fragment is translated medially and/or there is an ulnar nerve injury, while the lateral approach should be considered when the proximal fragment is displaced laterally. Performing an open reduction may increase the risk of elbow stiffness and/or heterotopic ossification, especially in cases presenting after a week.

Lateral Condyle Fractures

Fractures of the lateral humeral condyle are due to a fall on the outstretched arm, with traction on the extensor origin. In contrast to a supracondylar fracture, which presents with circumferential soft tissue swelling, lateral condyle fractures have isolated swelling over the lateral elbow. When the diagnosis is in doubt, the fracture is best visualized on an internal oblique radiograph (Fig. 27.9). These fractures may be complete (extend into the joint) or incomplete (retain an intact articular cartilaginous hinge) and either non-displaced or displaced. Complete fractures which are non-displaced remain at risk for displacement, and close follow-up is required. Non-displaced fractures or those with 1–2 mm displacement can be managed in a long arm cast with the forearm in supination to relax the extensor muscles. Weekly radiographs for up to 3–4 weeks are necessary to ensure maintenance of alignment.

Some fractures are angulated, with displacement at the metaphysis but no rotation of the fragment, suggesting an intact articular cartilaginous hinge. If an image intensifier is available, an arthrogram can be useful to determine if the fracture is intra-articular. These fractures can be managed in a cast after percutaneous pinning. Fractures with complete displacement require an open reduction and fixation with 2–3 K-wires, to align the displacement at both the physis and the joint surface. The wires are removed at 3–4 weeks, and a long arm cast is

Fig. 27.9 Displacement of a lateral condyle fracture is often best appreciated on an internal oblique radiograph

Fig. 27.10 Minimally displaced lateral condyle fracture

applied for an additional 2–4 weeks depending on the age of the child and the degree of healing (Fig. 27.10). Healing of lateral condyle fractures is often delayed with a risk of nonunion. The torn periosteum should be repaired if possible to reduce the risk of lateral spur formation. When available, a single compression screw through the metaphyseal fragment oriented from posterolateral to anteromedial can be used. This approach may decrease the time to healing, promote earlier motion, and reduce the risks of lateral overgrowth, but a second procedure is suggested to remove the implant.

Delayed union or nonunion without significant displacement may be managed by a compression screw which may be placed percutaneously or with a limited open realignment with or without bone grafting. Stiffness is a concern and patients may take months to regain maximal motion. Lateral condylar nonunion may be complicated by progressive valgus deformity and a tardy ulnar nerve palsy. Hyperemia or altered growth may result of overgrowth of the lateral aspect of the distal humerus (pseudovarus). A rare complication is avascular necrosis of the trochlea, which may be caused by posterior soft tissue stripping during dissection or injury from the fracture to the limited intraosseous vascular supply to the trochlear ossification center. The "fishtail" deformity may or may not be symptomatic, but in severe cases can be associated with progressive proximal migration of the ulna associated with radial head subluxation and degenerative changes. Treatment is individualized and may require debridement and surgical arrest of the proximal ulna.

Monteggia Lesions

Monteggia lesions involve a fracture of the ulna with a dislocation of the radial head. Four types are described based on the direction of the dislocation. A line drawn through the center of the proximal radius, in line with the radial shaft, should intersect the capitellum or capitellar ossification center in all x-ray projections. Re-establishing ulnar length and alignment is critical in maintaining radial head reduction in all Monteggia lesions. This must be confirmed by weekly x-rays for the first 3 weeks. Ulnar fixation is necessary when ulnar length and/or stability cannot be achieved. An intramedullary Steinmann pin or K-wire suffices for length stable fractures (Fig. 27.11). The K-wire can be removed in clinic after 3–4 weeks when a new cast is applied for an additional 2–3 weeks to allow soft tissue healing. A plate may be required if the fracture is comminuted or length unstable.

Fig. 27.11 (**a**) Displaced lateral condyle fracture treated by (**b**) open reduction and percutaneous fixation

In *Type I* lesions, the most common, the radial head, is dislocated anteriorly with an oblique greenstick or displaced fracture of the ulna, due to a fall on the outstretched arm with an extension stress at the elbow. Reduction involves (1) re-establishing ulnar length by correcting the angular deformity and (2) reducing the radial head, usually by flexing the elbow and occasionally applying a posteriorly directed force to the proximal radius. The patient is immobilized in a long arm cast in 110–120° flexion and neutral to mid-supination for 6 weeks, after which the patient is transitioned to a long arm splint and ROM exercises are begun.

Type II lesions are rare and involve an apex posterior angulated proximal ulna fracture and posterior dislocation of the radial head. Reduce these by extending the elbow and applying digital pressure to the proximal ulna. The radial head will usually reduce spontaneously. A long arm cast with the elbow in extension is applied.

The *Type III* pattern is a greenstick varus fracture of the olecranon and a laterally dislocated radial head. Reduce this by a valgus stress with the elbow in extension. If the reduction is stable, the elbow can be immobilized in a long arm cast with the elbow in 90° flexion. Recommendations for forearm rotation vary between pronation, mid-supination, and neutral. If the reduction is unstable or the fracture re-angulates, immobilize the extremity in a long arm cast with the elbow in extension and the forearm supinated.

The *Type IV* pattern consists of fractures of both the radial and ulnar shafts and radial head dislocation. Without a lever arm to help reduce the radial head, reduction requires ORIF. If surgical facilities and immediate referral are not possible, the best choice may be to treat both shaft fractures closed, addressing the radial head dislocation with open reduction and annular ligament reconstruction, usually with an ulnar osteotomy, at a later time.

Radial Neck and Olecranon Fractures

Fractures of the radial neck can be metaphyseal or physeal (Salter-Harris II) and angulated, translated, or both. Complications are frequent and include loss of motion (usually pronation), avascular necrosis, and radial head overgrowth. Up to 30° angulation and only 3–5 mm of translation are acceptable due to the risk of loss of forearm rotation. The authors favor reduction by the flexion-pronation maneuver, in which the elbow is held in 90° flexion, with the surgeon's thumb pressed against the radial head while the forearm is forcefully pronated. A long arm cast in 90° flexion and neutral rotation is worn for 3 weeks. An alternate technique involves placing a varus stress on the extended elbow while thumb pressure reduces the radial head. Open reduction should be avoided, if possible, owing to the high risk of stiffness, nonunion, heterotopic bone formation, and avascular necrosis.

If an image intensifier is available, consider percutaneous manipulation with the blunt end of a Steinmann pin or K-wire. A 3–5 mm incision is made close to the lateral border of the ulna and distal to the fracture. The blunt end of the wire is advanced up to the fracture site while the arm is pronated to minimize the risk of damage to the posterior interosseous nerve. If the fragment is only angulated, the wire can be introduced between the fragments and used to lever the fracture fragment and translate it into position. If that fails and the fracture is not translated severely, a flexible nail or intramedullary K-wire with an angulated tip can be introduced into the distal radius and advanced across the fracture site, manipulating the fragment with the K-wire to achieve reduction (Metaizeau technique).

Olecranon fractures involve either the apophysis or the metaphysis. Non-displaced fractures are managed in a long arm cast with the elbow in extension. Those with more than 2 mm displacement and/or joint step-off require open reduction and fixation. While a wire tension band is required in adolescents and adults, in children a heavy nonabsorbable suture may be used for the figure of eight loop.

Diaphyseal Fractures of the Radius and Ulna

These fractures have less potential for remodeling and require additional time for healing compared to more distal fractures. Fractures are classified by increasing completeness as (1) plastic deformation, (2) greenstick deformity, and (3) complete fractures. The reduction maneuver depends upon (1) location, (2) degree of completeness, and (3) direction of deformity. Cast molding is essential and wedging may be required.

Plastic deformation presents as an angular deformity or bend in the bone without an obvious fracture line. Reduction is achieved by placing a gradual and sustained force across the apex of the deformity. The end point occurs when alignment is restored clinically and forearm rotation is full. The reduction requires full general anesthesia or a good block. The above elbow cast must be well molded and is worn for 6 weeks.

In *greenstick fractures*, the cortex on the tension side fails completely, but the compression side cortex has only an incomplete fracture with plastic deformation. These fractures typically have both angular and rotational malalignment. In cases with apex volar angulation, the distal fragment is supinated relative to the proximal fragment, and pronation is required to reduce the fracture. In the opposite circumstance, an opposite maneuver is necessary. Correction of rotational malalignment usually corrects any angular deformity. Care must be taken to keep the elbow flexed to 90°, with good posterior molding along the distal humerus and proximal ulna to prevent the forearm sliding back into the cast. It is unclear whether the opposite cortex should be deliberately fractured during the reduction as the risks of creating an unstable fracture must be balanced against a possible reduction in the rate of refracture of healed angulated greenstick fractures.

Complete forearm fractures tend to be unstable in angulation, rotation, and length. Intact muscle forces are an important factor in producing deformity and need to be taken into consideration during reduction and reduction maintenance. To assess rotation on an AP radiograph, the bicipital tuberosity is oriented 180° opposite the radial styloid, and the coronoid process should be 180° opposite the ulnar styloid. A difference in diaphyseal widths at the two ends of the fracture also indicates rotational malalignment. These fractures need to be immobilized in a long arm cast for at least 4 weeks, followed by an additional 2–4 weeks in a below elbow, well-molded cast. Shortening of less than 1 cm is acceptable, as is bayonet apposition (Fig. 27.12) as long as forearm alignment is maintained.

The main indications for surgical intervention are (1) open fractures, (2) inability to achieve or maintain an acceptable closed reduction, and (3) displaced or unstable fractures in the setting of a second, ipsilateral fracture, especially supracondylar humerus (floating elbow). Options for stabilization include intramedullary fixation with flexible nails, K-wires, Steinmann pins, or plate fixation. Open reduction is required in the absence of image intensification (Fig. 27.13).

An ulnar IM wire can be placed via a small incision along the lateral aspect of the proximal ulna or from distal to proximal through a small opening in the distal ulnar metaphysis. The radial implant is inserted into the distal metaphysis either via a dorsal (between the second and third compartment) or radial approach (between the first and second dorsal compartments). Avoid injuring the distal radial physis and superficial radial nerve. The main risk of the dorsal approach, ulnar side of Lister's tubercle, is tendon injury, especially the extensor polli-

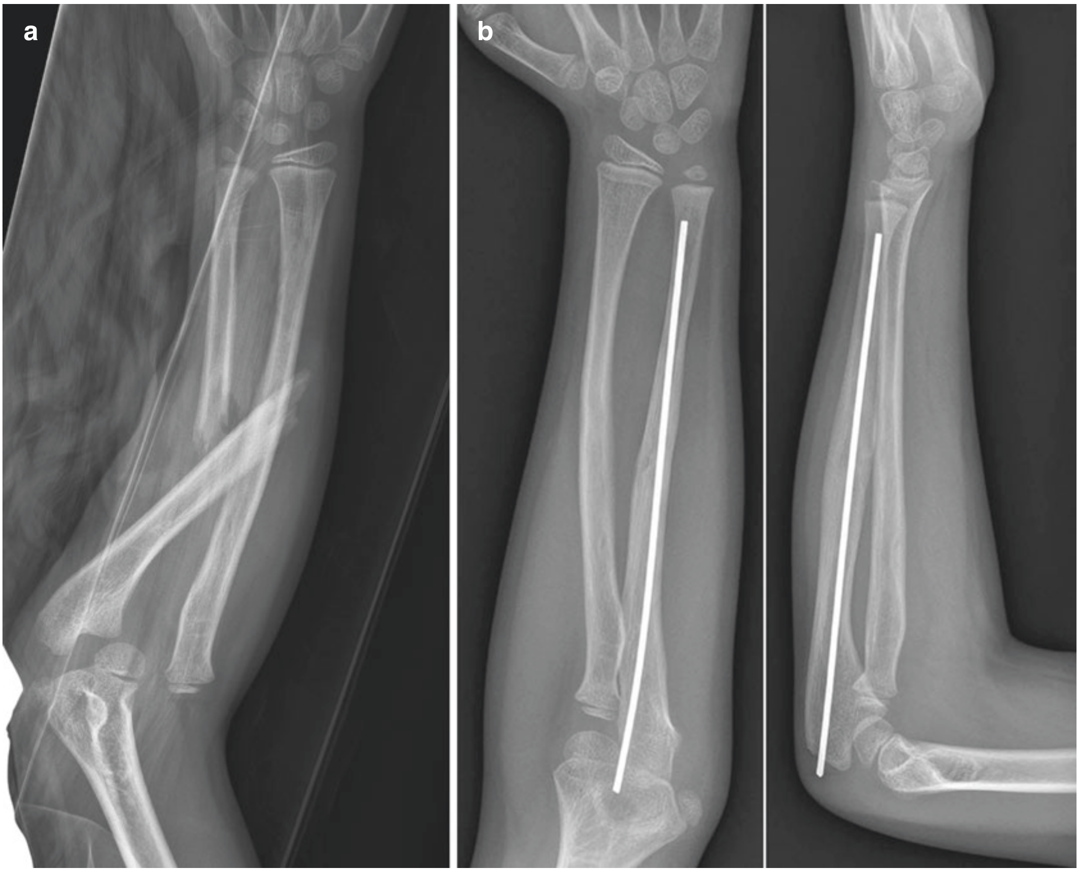

Fig. 27.12 (**a**) Monteggia fracture (Type I) with a widely displaced, oblique ulnar shaft fracture and anterior dislocation of the radial head (**b**) treated by closed reduction of radius and ulna and intramedullary fixation of the ulna with a Steinmann pin

cis longus. The risk may be lessened by ensuring that the distal aspect of the implant does not impinge on any muscular or tendinous structure. The ulnar implant should be more rigid than the radial implant, and the radial implant should be pre-contoured to maintain the normal radial bow.

Distal Radius Fractures

Both volarly and dorsally angulated and displaced fractures, involving the metaphysis or physis, can be expected to remodel approximately 0.9° of sagittal malalignment per month and 0.8° of radial deviation. The majority can be managed non-operatively, with the exception of (1) open fractures, (2) displaced intra-articular fractures, (3) irreducible fractures due to interposed tissues, (4) a more proximal ipsilateral fracture, and (5) acute carpal tunnel syndrome. While there is no conclusive evidence to support the use of a long versus short arm cast, some surgeons prefer a long arm cast for the first 2–3 weeks transitioning to a short arm cast once early healing is observed.

Distal radius physeal fractures with up to 50% displacement have an excellent potential for remodeling, as long as 1.5 years of growth

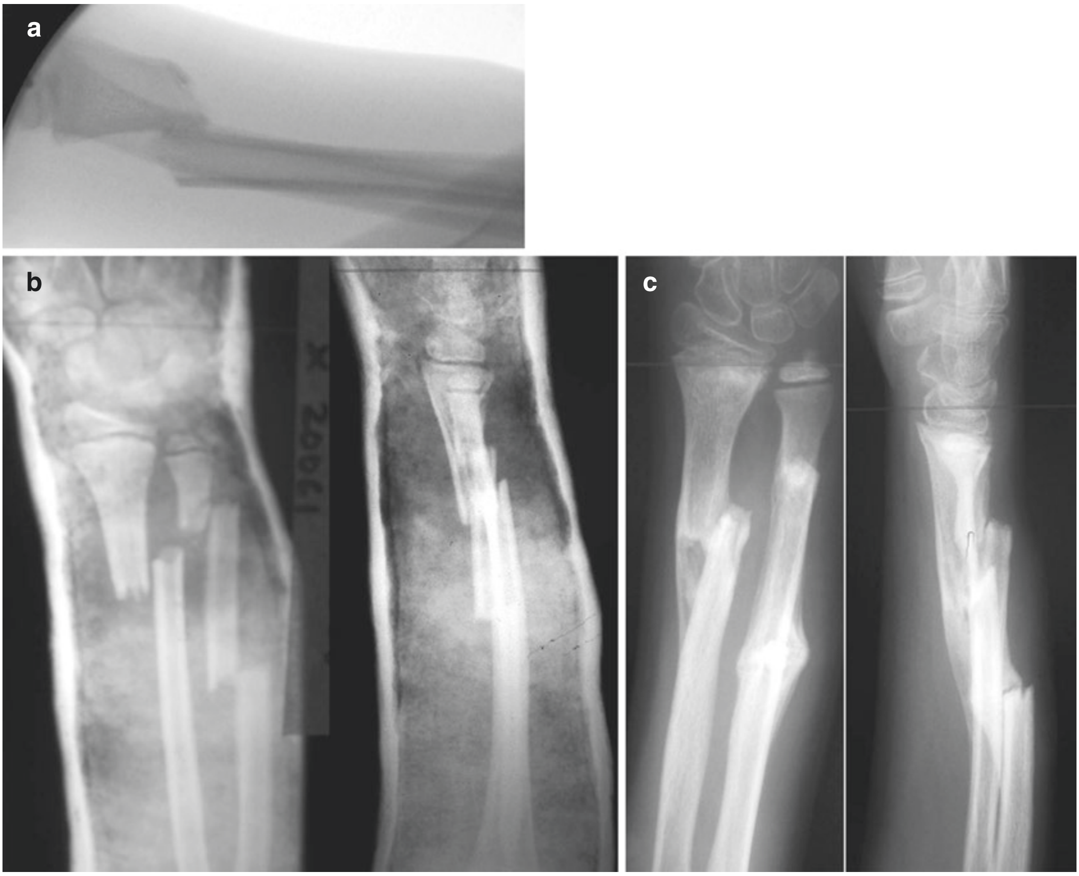

Fig. 27.13 (**a**) Bayonet apposition is acceptable as long as alignment is adequate. (**b**, **c**) Complete segmental diaphyseal radius and ulna fractures with bayonet apposition treated by closed reduction and casting

remain. Major concerns with displaced physeal fractures are carpal tunnel syndrome and growth arrest. Distraction with finger traps or gentle counter traction can often reduce these fractures, and in some cases it is necessary to apply dorsal pressure on the distal fragment. The risk of growth disturbance is increased substantially when reduction is performed more than 1 week following injury or with repeated attempts.

Displaced distal radial metaphyseal fractures are less stable than distal physeal or greenstick fractures and are prone to re-displace after reduction especially when the ulna remains intact. Reduce them by hyperextending the distal fragment and apply traction to restore length. Once length is re-established, angulation is corrected by volar flexing the distal fragment on the proximal fragment. The fracture is casted for at least 6 weeks. Dorsal bayonet apposition of both radius and ulna can be expected to remodel in children less than 12 years of age, but adequate alignment must be maintained.

Displaced *distal ulnar physeal* fractures are complicated by growth arrest in up to 50% of cases, and patients should be followed for at least 1 year. Growth arrest can result in ulnar negative variance and subsequent deformity of the distal radius and ulna. Depending on remaining growth, a distal radial epiphysiodesis should be considered if ulnar physeal closure has been identified.

Torus or buckle fractures are incomplete metaphyseal fractures and can be treated by simple immobilization in a plaster splint or back slab for 3–4 weeks.

Neglected Upper Extremity Fractures/Dislocations

Displaced *supracondylar humerus fractures* are difficult to manage after a few days and soft callus has formed. The management of cases in which closed treatment is no longer possible, but healing is incomplete, remains controversial. Traction is most successful when started within the 1st week but may be effective in some patients at 2–3 weeks following injury. Skeletal traction is preferable to skin traction as greater weight can be used. Healing in varus malalignment is a risk.

The risk of complications such as stiffness and heterotopic ossification is increased when open reduction is done during the early, inflammatory phase of fracture healing (Fig. 27.14), and it may be prudent to consider a corrective osteotomy after the fracture has completely healed. An alternative is "early" osteotomy, performed after 4 weeks but before complete healing. Removal of an anterior bone block, cheilectomy, can be

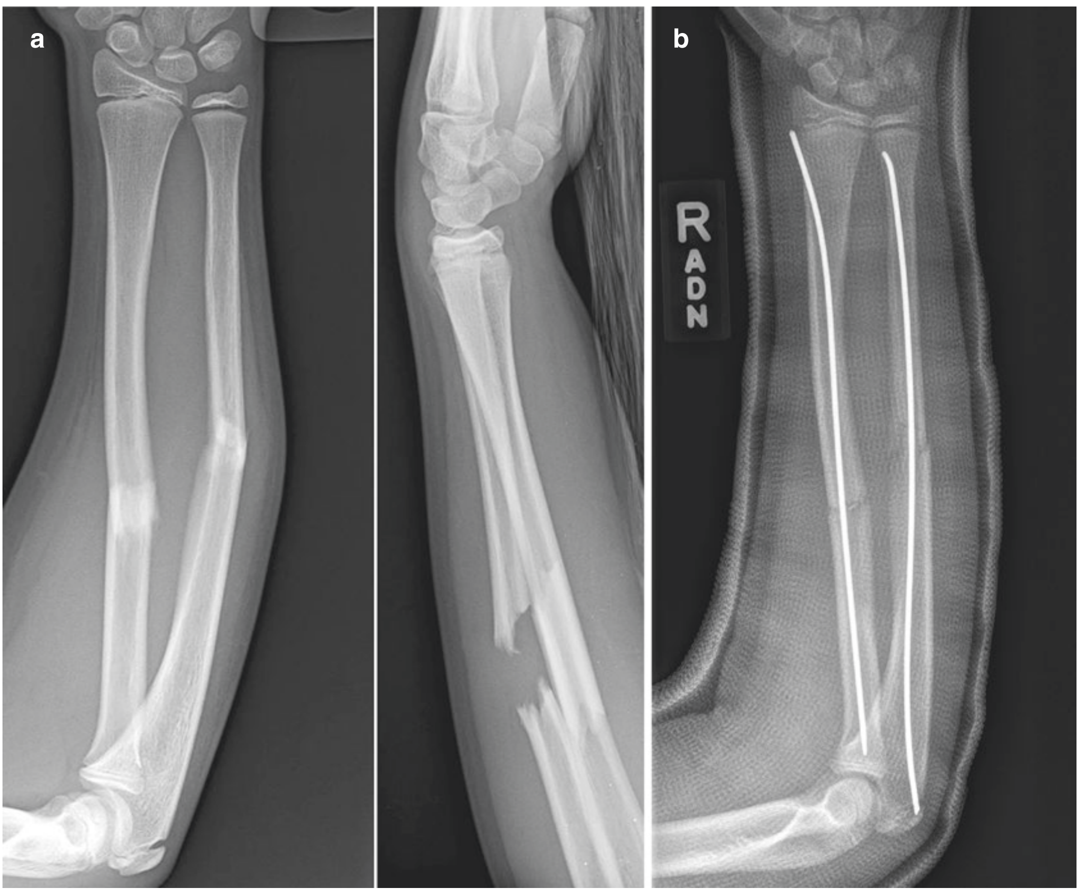

Fig. 27.14 (**a**) Unstable diaphyseal forearm fracture treated by (**b**) nailing

Fig. 27.15 This child (**a**) presented for treatment 12 days following Type III supracondylar fracture with early callus and was treated by (**b**) open reduction and percutaneous fixation. There is an increased risk of heterotopic ossification and stiffness with open treatment at this stage of fracture healing

considered when the primary problem is lack of flexion due to impingement (Fig. 27.15). The most common approaches for an osteotomy are lateral and posterior.

Untreated fractures of the *lateral humeral condyle* can result in chronic pain, loss of motion, instability, and cubitus valgus with or without tardy ulnar nerve palsy. Surgical treatment should be directed to relieving symptoms and/or improving function, given the surgical risks of stiffness, avascular necrosis, and persistent nonunion. Observation may be appropriate for asymptomatic patients with normal function, recognizing that valgus deformity and/or discomfort can develop over time.

An anatomic reduction is unrealistic given the associated soft tissue contractures and remodeling of the bony surfaces. Any extensive dissection, especially posteriorly, may de-vascularize the fragment leading to avascular necrosis and persistent nonunion. Rather than an anatomic reduction, the goal is union in a position that maximizes range of motion and provides the best carrying angle.

A posterolateral approach is used, with either local or iliac crest bone graft. Triceps lengthening can improve flexion. Fixation is with K-wires, a tension band, or screw, avoiding the physis (Fig. 27.16a–c). A varus producing distal humeral osteotomy and/or ulnar nerve transposition may be required to correct cubitus valgus and tardy ulnar nerve palsy and can be performed either with or without an attempt to achieve union (Fig. 27.17). There are no guidelines to suggest a time after which surgical treatment should not be considered.

Fig. 27.16 (**a**–**c**) A common problem associated with untreated displaced supracondylar fractures is an osseous flexion block. (**d**) Cheilectomy is one treatment option. (**e**) Increased flexion on the table. (**f**) Post-op x-ray

Fig. 27.16 (continued)

While untreated *Monteggia lesions* may present with reasonable motion and function, requiring only observation, they more commonly present with pain, decreased range of motion, deformity, and/or elbow instability. Satisfactory outcomes after reconstruction have been achieved up to 3 years post-injury. The surgery involves open reduction of the radial head with or without annular ligament reconstruction and an ulnar osteotomy for realignment and lengthening (Fig. 27.18).

Re-establishing ulnar alignment and length are critical in maintaining reduction of the

Fig. 27.17 This (**a**) untreated lateral condyle fracture went on to a painful nonunion and was treated by (**b**) in situ stabilization with a screw and local bone graft. Valgus was present but was not of concern to the patient. (**c**) The fracture healed and the patient was asymptomatic despite some loss of motion

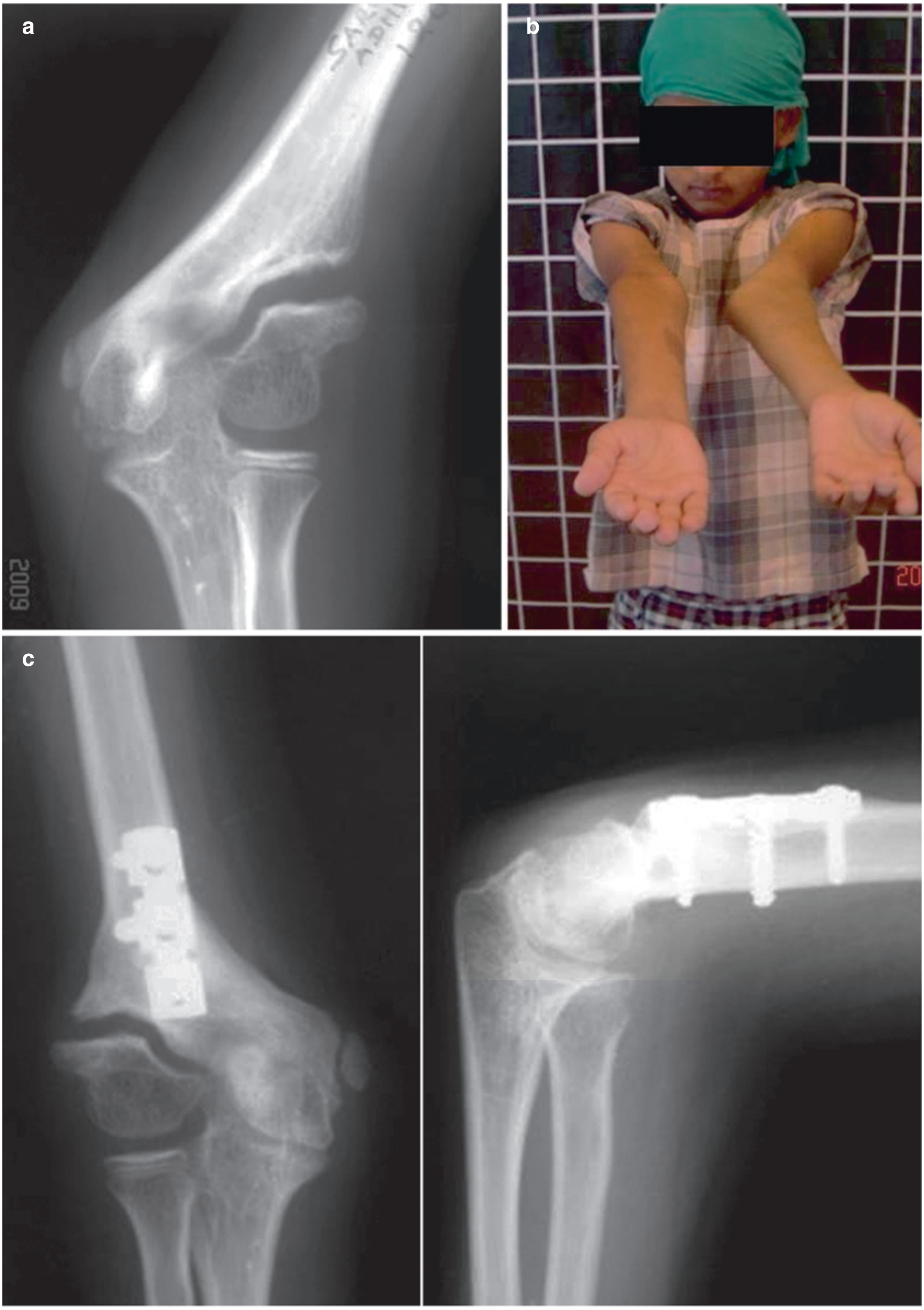

Fig. 27.18 Another approach to the (**a**, **b**) ununited lateral condyle fracture associated with significant valgus alignment is to perform a (**c**) corrective osteotomy without an attempt to achieve union of the fracture fragment

radial head. An osteotomy of the radius is rarely required. Annular ligament reconstruction can be done using fascia from the triceps, a free tendon or fascial graft, or non-resorbable suture. The K-wire or Steinmann pin used to maintain radiocapitellar reduction is removed after 2 weeks. Rarely, the radial head may reduce with restoration of ulnar length and alignment alone. Another option is an external fixator to lengthen the ulna following osteotomy, with or without open reduction of the radial head.

Symptomatic chronic radial head dislocations can be treated by excision when reconstruction is not feasible, for example, when deformity of the radial head results in an incongruous relationship with the capitellum. Complications of these procedures include re-subluxation or re-dislocation of the radial head, ulnar neuropathy, nonunion, compartment syndrome, and stiffness, especially loss of pronation.

Patients with a neglected *elbow dislocation* commonly present with pain, restricted

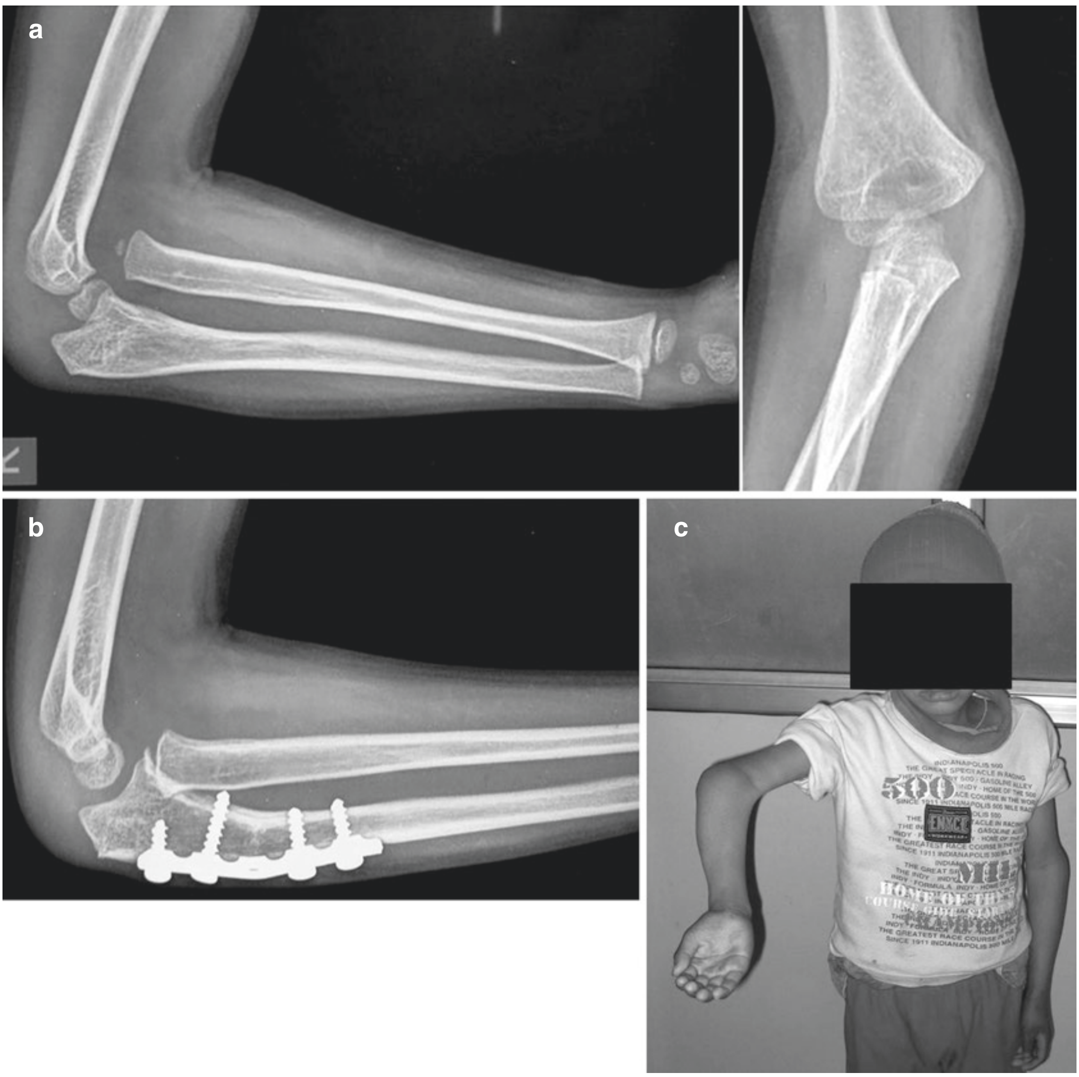

Fig. 27.19 This (**a**) untreated Type I Monteggia lesion underwent (**b**) corrective osteotomy to restore ulnar length, followed by open reduction of the radial head and annular ligament reconstruction. This patient presented with a (**c**, **d**) neglected Type III Monteggia fracture, a very difficult treatment challenge

Fig. 27.19 (continued)

motion, and limitation of function (Fig. 27.19). Treatment options include primary open reduction, external fixation with or without open reduction, and salvage procedures such as excisional arthroplasty or arthrodesis. Open reduction is the most common treatment. Barriers to reduction include contracture of the periarticular soft tissues and collateral ligaments, soft tissue calcification, and intra-articular fibrous tissue.

Careful dissection is required as osteopenia and articular cartilage softening make tissue differentiation difficult, risking joint damage. A posterior approach with triceps V-Y lengthening and isolation of the ulnar nerve facilitates removal of the barriers to reduction. A K-wire crossing the ulno-humeral joint holds the reduction. Active assisted range of motion exercises are started at 2 weeks when the K-wire is removed. Complications include transient ulnar nerve palsy, contracture, infection, and heterotopic ossification. The results are less satisfactory when a coexisting fracture is present. Joint space narrowing and signs of early arthritis are often observed on radiographic follow-up; however, it is unknown if and when these findings affect the clinical results (Fig. 27.20).

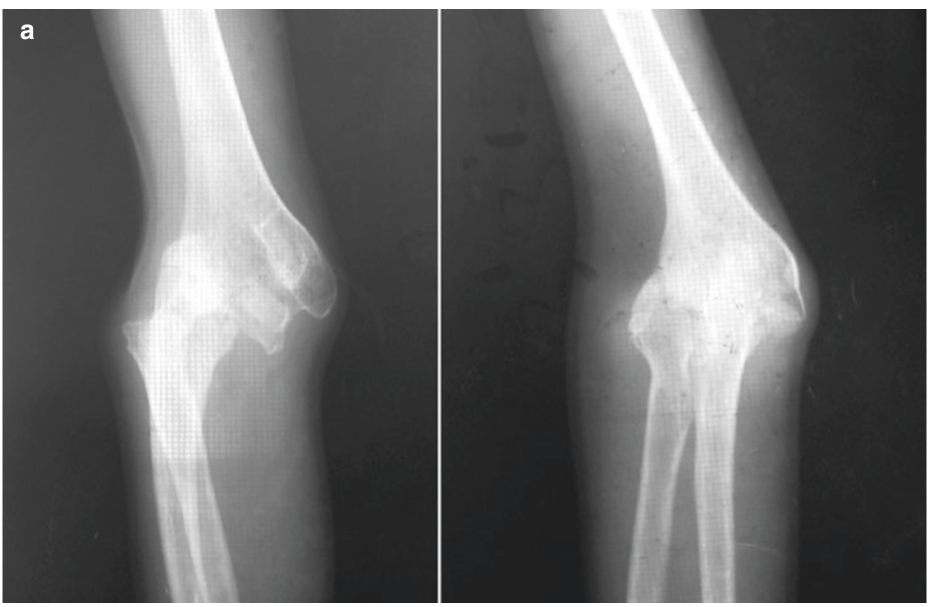

Fig. 27.20 This patient with a (**a**) neglected elbow dislocation presented with (**b**) loss of motion but without pain or restrictions in activities of daily living

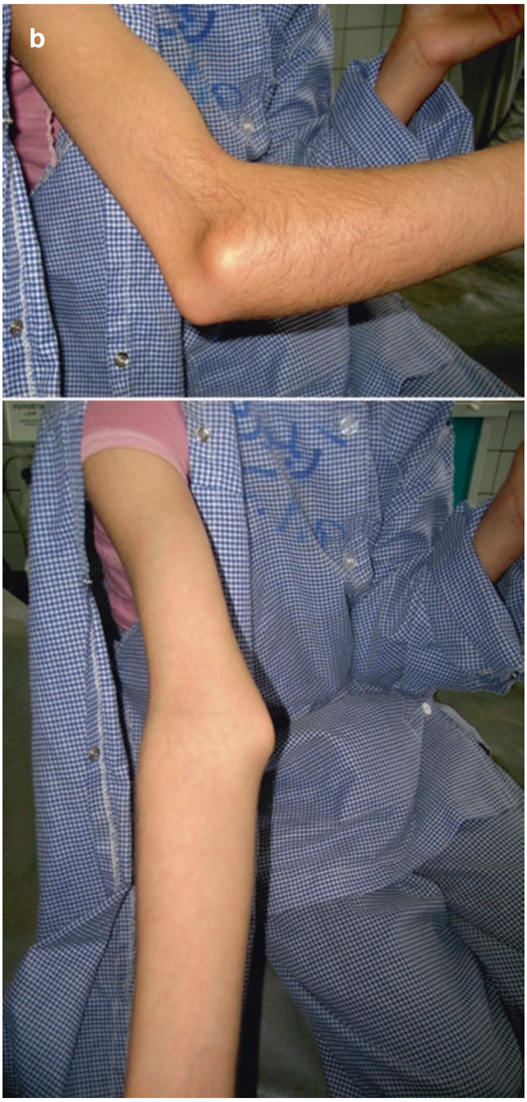

Fig. 27.20 (continued)

Acknowledgment The authors would like to acknowledge Dr. Kaye Wilkins for a lifetime dedicated to improving the care of children with musculoskeletal injuries globally and also for his contributions to this chapter in the first edition of this book.

Additional Resources

A variety of printed materials and videos are available on the Global HELP website. https://global-help.org/category/specialties/ped-orthopaedics/trauma/.

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28 Management of Lower Extremity Fractures

David A. Spiegel and Bibek Banskota

Femoral Shaft Fractures

A variety of options are available for managing pediatric femur fractures. Treatment is based on the age of the child, mechanism and energy of the injury, personality of the fracture, and local resources. Choices include (1) immediate spica casting, (2) traction alone or traction followed by spica, (3) closed or open reduction and intramedullary fixation, (4) open reduction and plating, and (5) external fixation. An average of 9 mm overgrowth is commonly observed in children between 3 and 8 years, and shortening up to 2 cm is commonly accepted in children less than 10 years. Both overlap and angulation can contribute to limb shortening. The amount of shortening is best evaluated on lateral radiographs.

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Management in Children Less Than 6 Years Old

In general, femur fractures in children less than 6 years of age can be managed by closed reduction and immediate double- or single-leg spica casting (Fig. 28.1). A single-leg spica is useful in low energy injuries and affords greater mobility and increased ease of care, and many patients will ambulate once early healing occurs. Care should be taken to mold the cast into mild valgus as many patients lose some correction, drifting toward varus malalignment. Follow-up radiographs should be obtained weekly early periosteal callus. If alignment is inadequate, the cast can be wedged or changed. If shortening becomes unacceptable, traction or an external fixator can be considered, with or without osteoclasis, to facilitate restoration of length.

High-energy, comminuted, and short oblique fractures are often length unstable and require skeletal traction for 10–21 days before application of a spica. Proximal shaft fractures must be casted in 70–90° hip flexion as the proximal fragment is pulled into flexion by the psoas muscle. If traction is used, 90–90° traction is required (Figs. 13.16 and 28.2). Midshaft fractures can be casted in the midrange of hip flexion. The authors' preference is to leave the foot out of the cast.

Without portable imaging when the patient is treated in traction, limb lengths must be evalu-

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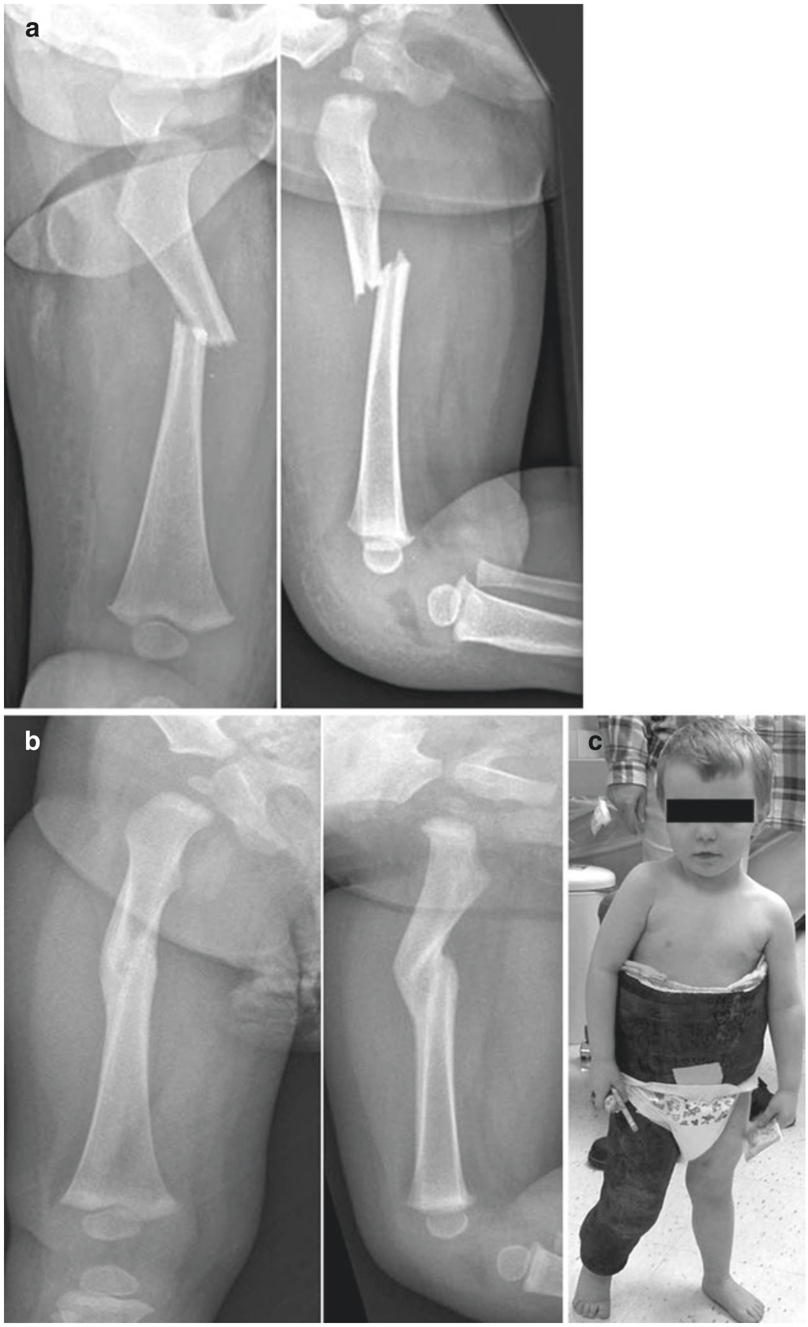

Fig. 28.1 (**a**, **b**) A proximal femoral diaphyseal fracture treated by closed reduction and immediate spica casting healed in adequate alignment, anticipating future remodeling. (**c**) Child walking in single-leg "walking spica" cast. The patient is wearing two diapers, one totally inside the cast

ated by clinical examination, taking care to avoid distraction. Ideally the affected limb will be shortened 1–1.5 cm to account for the expected overgrowth. When the fracture can be gently squeezed without pain, healing is sufficient for casting.

Six Years Through Skeletal Maturity

Controversy surrounds the optimal management of patients from 6 years through skeletal maturity, and the best approach depends on the availability of a suitable environment for open surgery,

Fig. 28.2 90–90 traction is considered for 14–21 days in length-unstable fractures, aiming for 1–1.5 cm of shortening in children between 3 and 8 years of age

portable radiographs or an image intensifier, and implants. Children in austere environments are often smaller with less muscle mass and bulk than their western chronological counterparts, skewing treatments to non-operative choices normally recommended for chronologically younger patients. Traction is an acceptable choice for any age. Proximal shaft fractures require 90–90° traction, and midshaft fractures can be treated in balanced skeletal traction with the hip in less flexion. Distal shaft fractures are more difficult to manage in traction, as the pull of the gastrocnemius on the distal fragment results in posterior sag. In addition to a longitudinal traction vector through the proximal tibia, with care to avoid the physis, a second traction pin is needed in the distal fragment with the force vector directed anteriorly to counter the pull of the gastrocnemius (see Fig. 13.22).

Some distal shaft fractures may be amenable to fixation with crossed Kirschner wires or Steinmann pins, but the two wires should not cross the fracture at the same point as stability will be inadequate. Implants placed from distal to proximal may be intra-articular, risking septic arthritis. To avoid this one can start fixation proximally though this must pass through thicker soft tissues and care must be taken to avoid the femoral artery for the medial fixation. These implants can usually be removed in the clinic setting.

The majority of length-stable fractures—transverse and mid-diaphyseal, in patients less than 50 kg—can be treated with an intramedullary implant. While flexible nails are unavailable in many settings (Fig. 28.3), a Rush rod can be used, recognizing that a spica cast is often required for rotational stability. An open reduction is usually required in the absence of an image intensifier, especially if the patient presents after a few days. A single Rush rod can be inserted through the tip of the greater trochanter and advanced across the fracture. Alternatively, two pre-contoured rods

Fig. 28.3 Flexible nailing for a diaphyseal femur fracture

can be inserted from the distal metaphysis and advanced proximally. When flexible nails are used to manage distal diaphyseal or meta-diaphyseal fractures, consider inserting the devices proximally, with lateral entry in the trochanteric region above the lesser trochanter, with one nail pre-contoured into a “C” shape and the other contoured and rotated into an “S” shape. Avoid piriformis fossa entry in any proximal nail, flexible or rigid, in the skeletally immature due to the risk of avascular necrosis. Flexible nails may also be used to manage proximal diaphyseal fractures, and they are both inserted in the distal metaphysis with the medial nail extended up into the femoral neck and the lateral nail up to the tip of the greater trochanter. Care must be taken to avoid perforation proximally, and images in different degrees of rotation may help avoid this situation.

External fixators can be viewed as portable traction and are especially beneficial for open fractures needing wound care. Use two half pins per fragment, and place them at least 3–4 cm from the fracture (Fig. 28.4). The resulting semirigid fixation allows micromotion, which

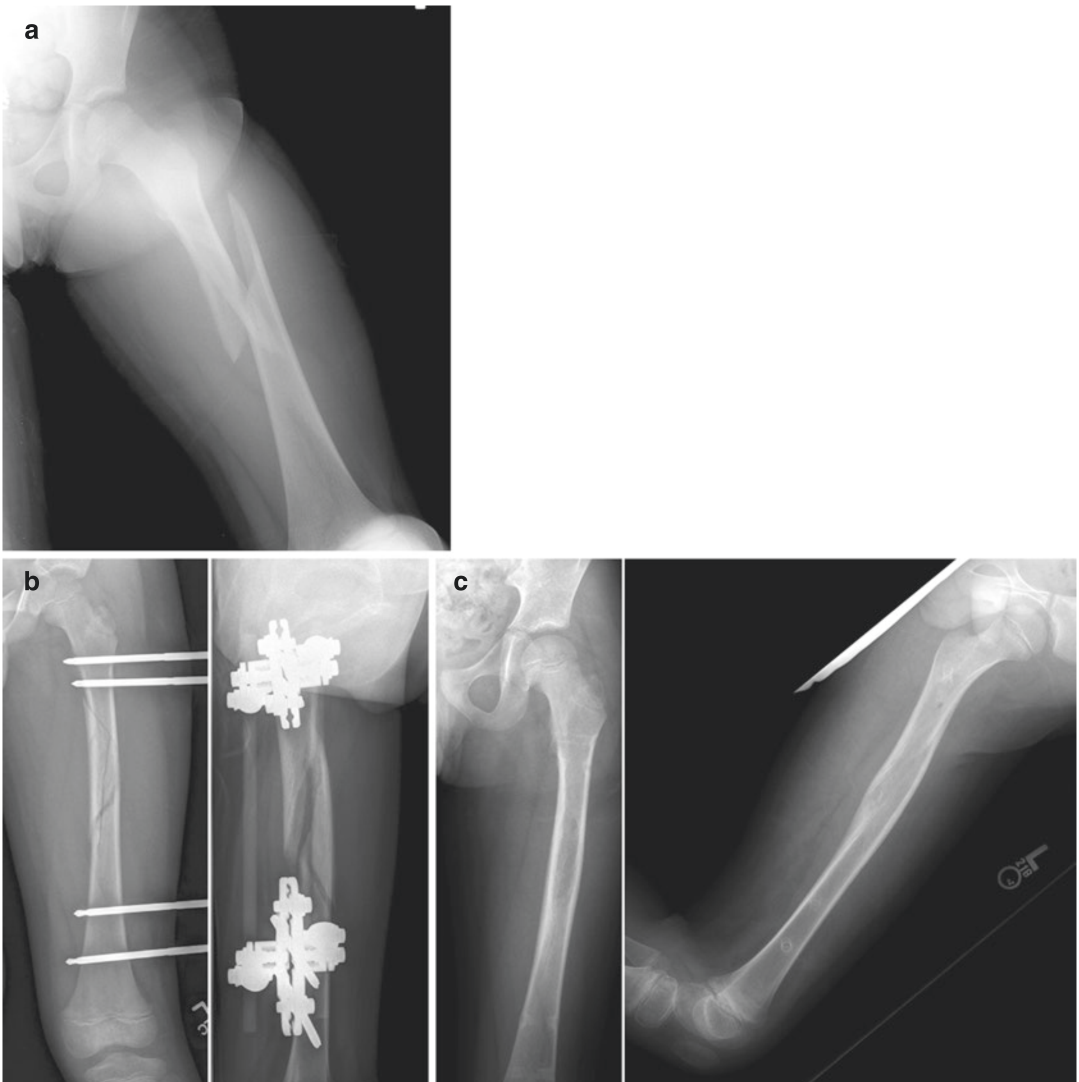

Fig. 28.4 (**a**) This length-unstable diaphyseal fracture was treated by (**b**) external fixation and (**c**) healed in satisfactory alignment

stimulates callus. When more rigidity is needed, external fixation principles for adult fractures can be used based on individual experience and judgment. Disadvantages of external fixation include the risk of refracture, especially in transverse fractures; pin tract infection or sepsis if adequate hygiene cannot be provided when the patient returns home; and the need for a second procedure to remove the fixator. The risk of infection due to contaminated pin sites is likely greater when a fixator is converted to an intramedullary device. Open reduction and plating is an option with an increased risk of infection compared with other treatments. This approach may be best suited for distal meta-diaphyseal fractures, and care must be taken to place the distal end of the implant more than 2 centimeters from the physis to reduce the risk of a progressive valgus deformity from physeal growth disturbance.

Tibia and Fibula Fractures

The majority of tibial shaft fractures, with or without fibular fracture, are amenable to closed management. These fractures are at risk for valgus angulation due to the pull of the anterior compartment muscles, and the remodeling potential is more limited for fractures with valgus and/or apex posterior angulation. Shortening up to 1 cm is acceptable, recognizing that the average overgrowth is 5 mm in children between 2 and 10 years. Fifty percent apposition of the fragments is acceptable (Fig. 28.5). Unstable fractures requiring reduction are commonly managed in a long leg

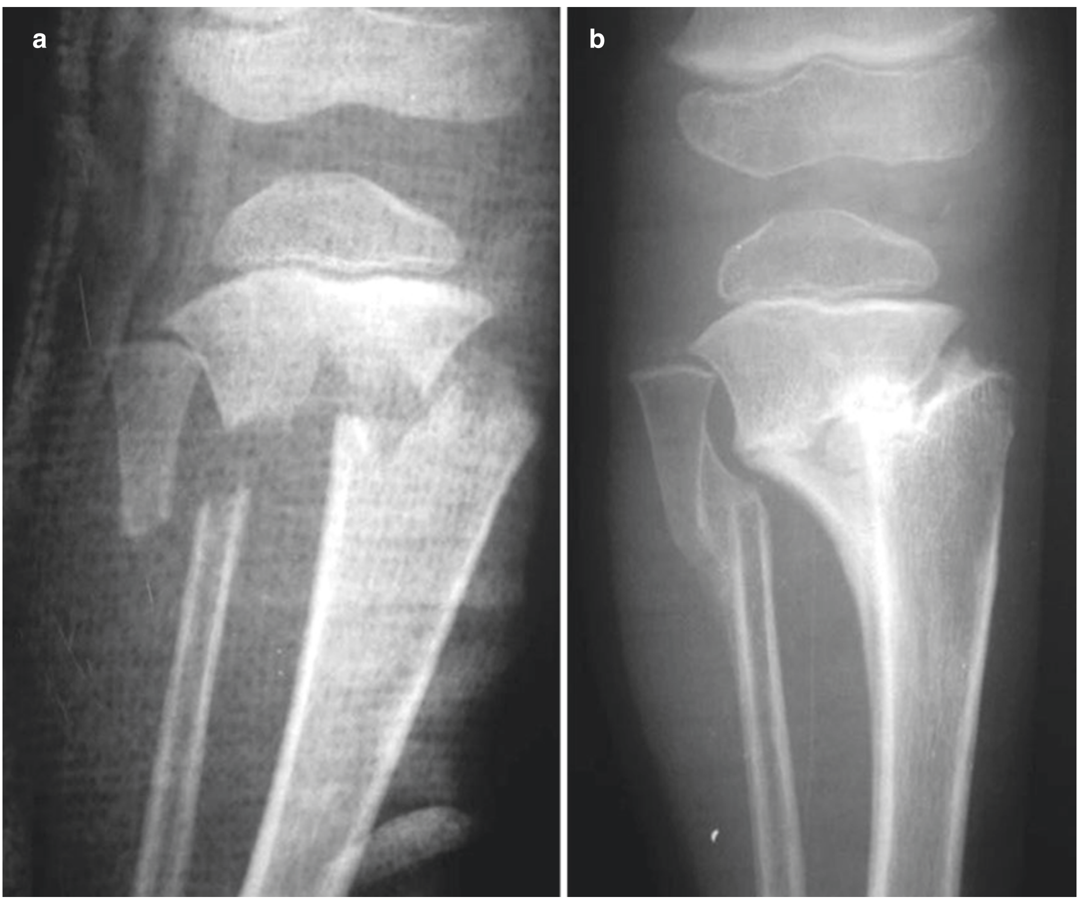

Fig. 28.5 This proximal tibial fracture was treated closed after manipulation to correct the valgus and healed in acceptable alignment although translation was >50%. The patient was asymptomatic. (**a**) Initial X-ray. (**b**) After reduction and 6 weeks casting

cast for the first few weeks, with transition to a short leg, weight-bearing cast once early callus has formed. Weekly radiographs are required for 2–3 weeks or until callus is present. At any time in the early treatment, cast wedging may be necessary to maintain alignment (see Chap. 13).

The risk of compartment syndrome is increased for direct, blunt trauma, as well as high energy injuries. In austere settings compartment syndrome must be diagnosed clinically, and the index of suspicion is heightened by agitation and increasing requirements for pain medicine.

Indications for operative management include open injuries, inability to achieve or maintain a closed reduction, neurovascular injury, compartment syndrome, and floating knee injuries. Treatment options include traction, closed reduction, and percutaneous fixation with a K-wire or Steinmann pin in proximal or distal metaphyseal fractures (Fig. 28.6), external fixation, intramedullary fixation, and open reduction and plating. Traction is rarely required when an external fixator is available but can be delivered via a calcaneal or distal tibial pin. External fixation is ideal for open fractures requiring wound management, recognizing that the time to union is increased, and complications are frequent especially following open fractures. The fixator should be either dynamized or removed as soon as soft tissue healing allows.

When available, intramedullary fixation with a flexible nail or a Rush rod can be considered for both closed fractures and grade 1 or 2 open fractures (Fig. 28.7). Pre-contoured flexible

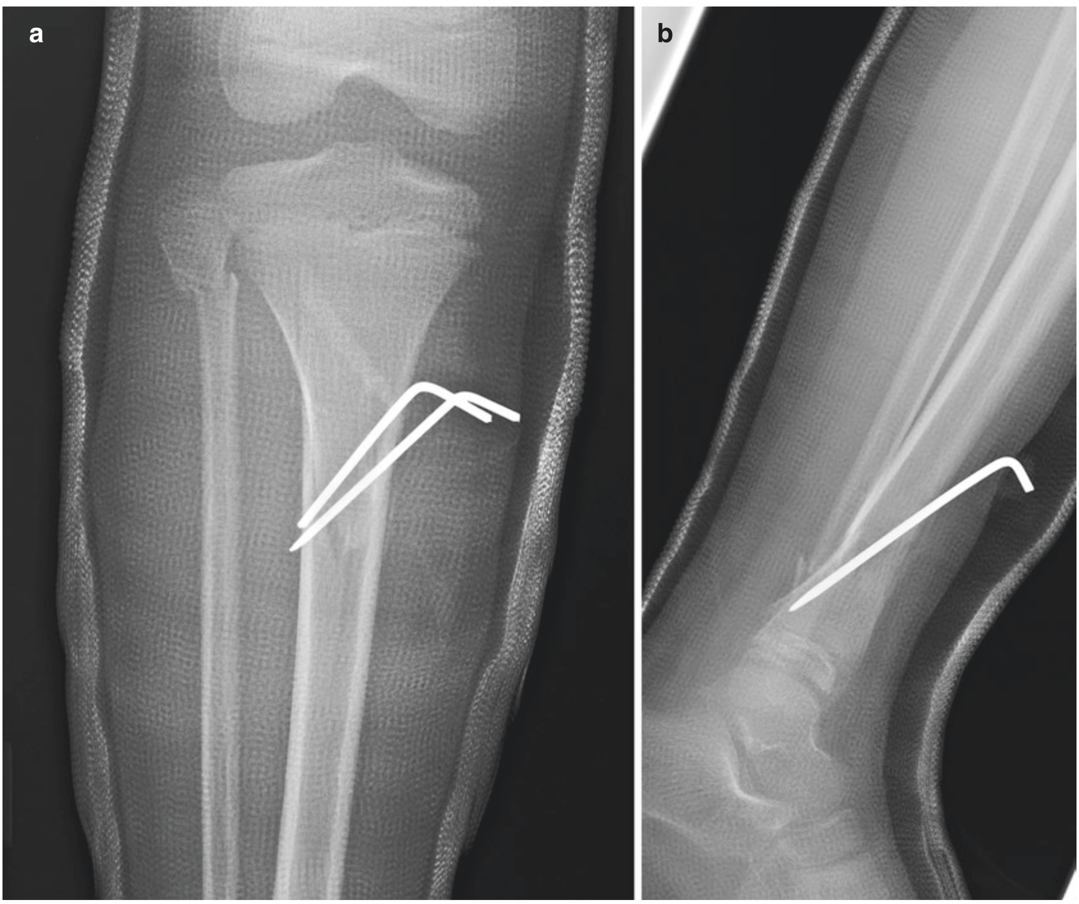

Fig. 28.6 (**a**) Percutaneous fixation can be used to maintain alignment in unstable proximal or (**b**) distal tibial fractures

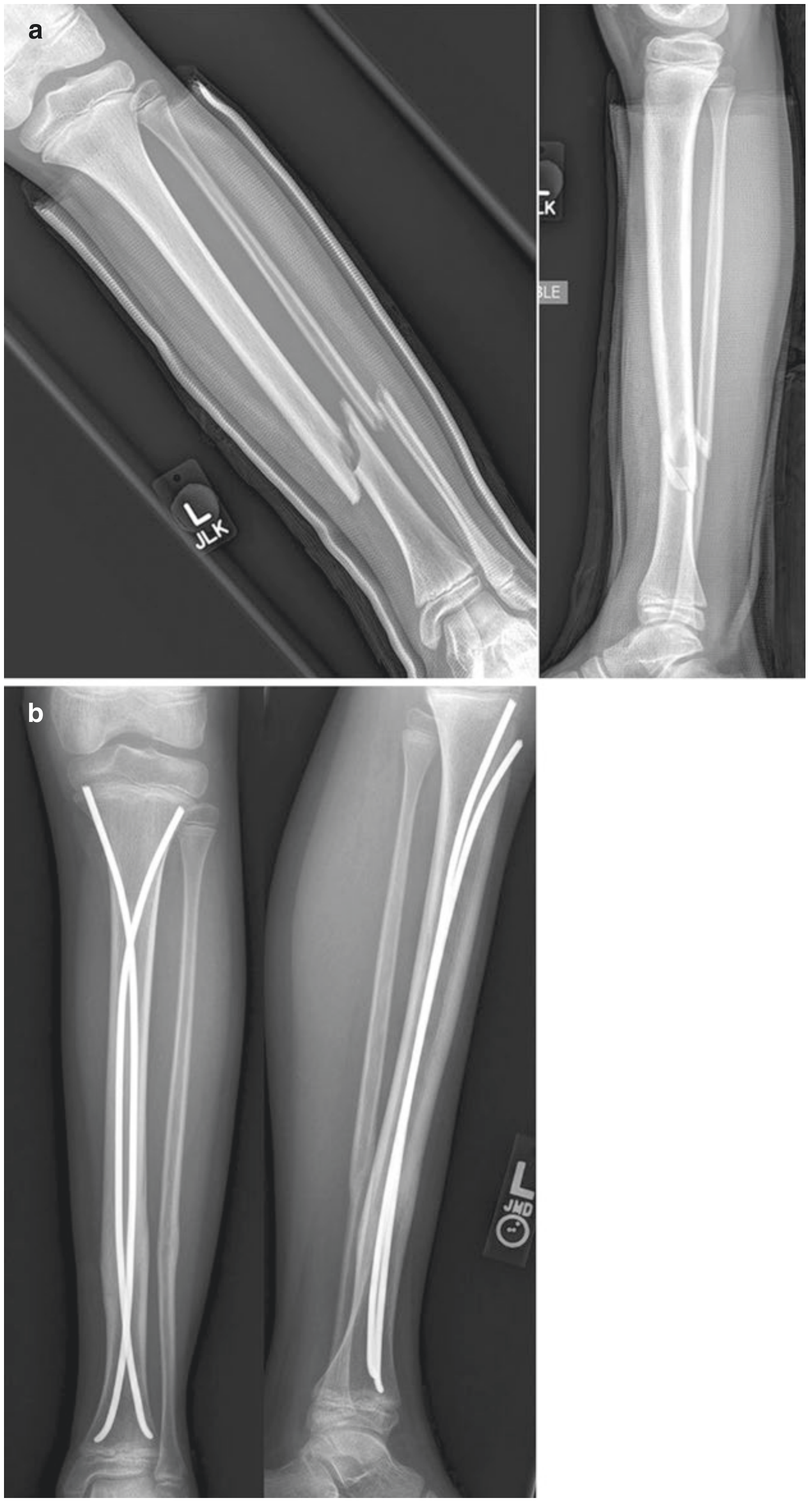

Fig. 28.7 (**a**) Unstable tibial shaft fracture (**b**) treated by flexible intramedullary nailing

nails, each less than 40% of the diameter at the isthmus, are inserted through two small incisions over the proximal tibial metaphysis and advanced across the fracture into the distal metaphysis but not across the physis. An open reduction is often required in the absence of an image intensifier. Procurvatum, anterior apex bowing, is common with standard nail positioning, and we recommend that the tips of the nails be rotated anteriorly to avoid this. Time to union is reduced when compared to treatment with external fixation, and complications are less frequent. Open reduction with extensive subperiosteal stripping and plate fixation should be avoided due to the risks of delayed union, nonunion, and wound sepsis. Complications are frequent in higher-energy, open fractures.

Ankle Fractures

Pediatric ankle fractures are most commonly classified according to Dias and Tachdjian based on the position of the foot at the time of injury and the direction of the force or stress as (1) supination-inversion, (2) pronation-eversion-external rotation, (3) supination-external rotation, and (4) supination-plantar flexion.

In the supination-inversion pattern (Fig. 28.8), the lateral side fails first in tension, resulting in a Salter-Harris type I or II fracture of the distal fibula. With greater force, the talus is driven into the medial malleolus, producing an oblique fracture (Salter-Harris III or IV). There may be comminution and/or impaction of the distal tibial articular surface. Open reduction of these intra-articular malleolar fractures is required if displaced >2 mm. The risk of growth disturbance is significant especially in younger patients, and they should have a radiographic follow-up in 4–6 months to evaluate the physes.

In the pronation-eversion-external rotation pattern, the medial side fails in tension, resulting in a Salter-Harris type I or II fracture of the distal tibia, associated with a transverse or oblique fracture of the distal fibula above the syndesmosis (Fig. 28.9). These present with valgus angulation. Periosteum may be trapped within the distal tibial fracture resulting in physeal widening. It is unclear whether routine removal of the periosteum is required to reduce the risk of growth disturbance; however, it should be removed if it prevents an adequate reduction.

The supination-external rotation pattern involves a Salter-Harris I or II fracture of the distal tibia associated with an oblique fracture of the distal fibular metaphysis (Fig. 28.10). The major clinical deformity is external rotation, and the reduction is secured by internally rotating the distal fragment. If the fracture is unstable, a screw can be used to maintain the reduction.

The supination-plantar flexion pattern results in a Salter-Harris type I or II fracture of the distal tibia with the distal fragment displaced posteriorly and a greenstick fracture of the fibula (Fig. 28.11). These fractures are reduced by longitudinal traction with the ankle plantar flexed, while the distal fragment is pushed anteriorly. Periosteum is commonly interposed at the fracture site and may require removal. Inadequate reduction results in loss of ankle dorsiflexion with or without impingement. If unstable, these are held with metaphyseal tibial screws placed from anterior to posterior (Images Courtesy of Dr. Kaye Wilkins).

Closure of the distal tibial physis is asymmetric, starting on the medial side and progressing to the lateral side. The Tillaux fracture results in avulsion of the anterolateral corner of the distal tibial epiphysis—the portion of physis that is last to close—by the anterior inferior tibiofibular ligament (Fig. 28.12). The triplane fracture is a more complex variant of the Tillaux in which fracture lines are identified in the

Fig. 28.8 (**a**) The supination-inversion fracture pattern involving Salter-Harris IV fracture of the medial malleolus and a Salter-Harris I or II fracture of the lateral malleolus (**b**) was treated by open reduction and fixation. (**c**) X-ray after removal of implants

Fig. 28.9 (**a**) This pronation-eversion-external rotation fracture in an adolescent near physeal closure was (**b**) reduced and stabilized with a percutaneous wire. (**c**) Final X-rays show acceptable ankle alignment

coronal, sagittal, and axial planes (Fig. 28.13). Both of these injuries require reduction if there is more than 1 mm joint step-off or more than 2 mm displacement. While closed reduction can be attempted, many require open reduction and fixation.

Fig. 28.10 The supination external rotation pattern may clinically present with obvious rotational deformity of the distal lower extremity

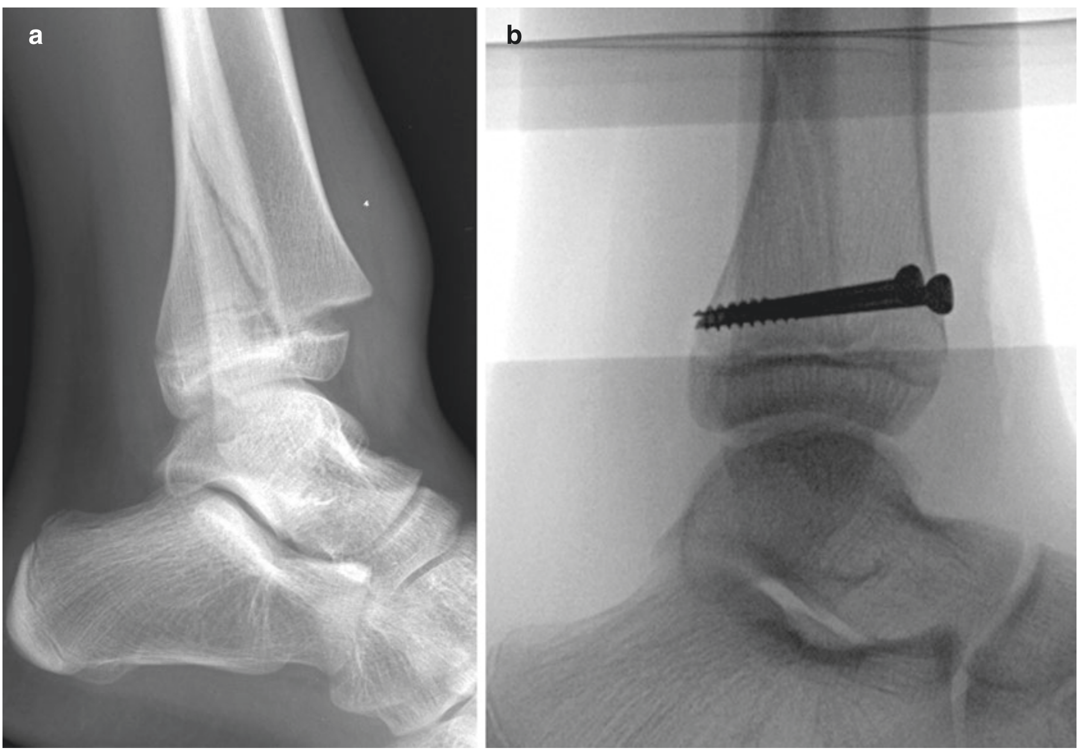

Fig. 28.11 (**a**) This supination-plantar flexion injury was treated by (**b**) reduction and screw fixation

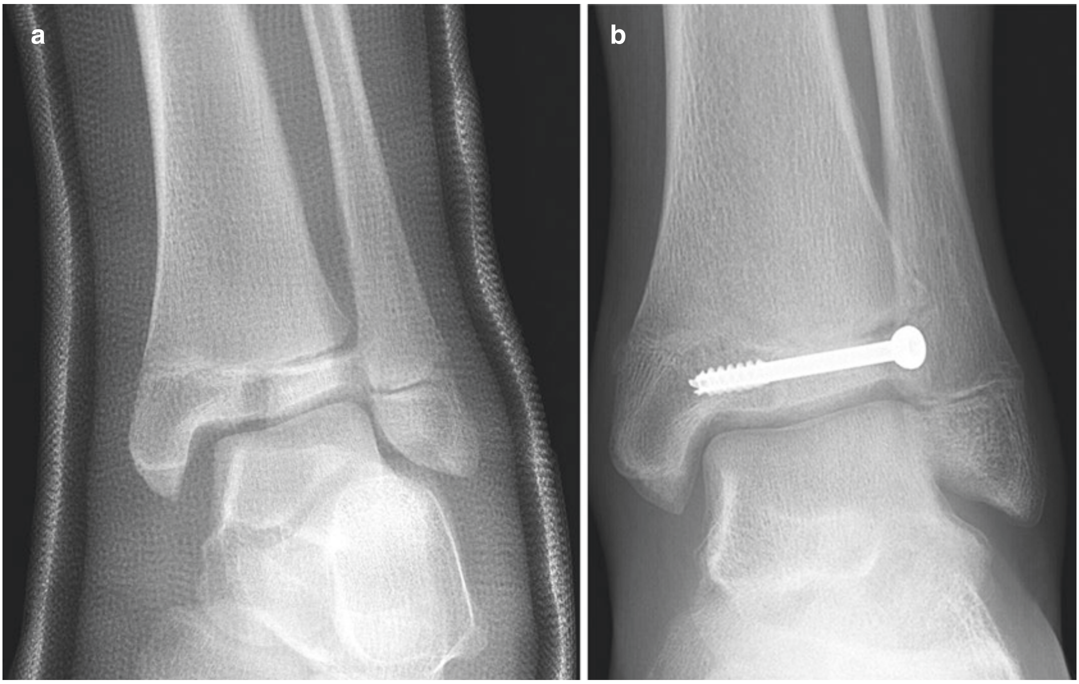

Fig. 28.12 (**a**) A juvenile Tillaux fracture treated by (**b**) open reduction and fixation

Neglected Lower Extremity Fractures and Fracture/Dislocations

Malunited diaphyseal fractures are treated by percutaneous or open osteoclasis or osteotomy, followed by traction/casting or fixation. Limb length discrepancies may require additional treatment after union. The basic principles of angular correction must be followed (see Chap. 37). If significantly displaced, malunited intra-articular fractures may require osteotomy with reduction and fixation. In addition one must anticipate and manage growth disturbance.

The management of *neglected femoral shaft fractures* centers on restoring limb alignment and length caused by angulation and/or overriding fragments. Soft-tissue contractures develop rapidly, making it difficult to restore length while correcting the deformity. An acute correction is possible, but lengthening more than 4 cm increases the risk of neurovascular complications. In fractures associated with osteomyelitis shortening may occur during debridement (Fig. 28.14).

A staged approach can be used, in which mobility of the fracture is achieved by osteoclasis, manually, percutaneously by drilling, or by open removal of the callus and bone, and length is restored by either 5 or 10 days of skeletal traction or distraction with an external fixator. Definitive stabilization is carried out once length has been restored, either by spica casting, internal fixation, or external fixation. Bone grafting with local callus or bone and/or iliac crest is recommended.

Femoral neck fractures are rare in children compared with adolescents or adults, and neglected injuries are prone to malunion or nonunion and avascular necrosis. While low-energy injuries are observed in children, higher-energy injuries predominate in adolescents and young adults. Primary strategies aim for union with preservation of the femoral head. Options include (1) bone grafting with internal fixation or (2) osteotomy and internal fixation, with or without bone grafting (Fig. 28.15).

Most traumatic *hip dislocations* in children are the result of low-energy injuries, and

Fig. 28.13 An example of a displaced triplane fracture. (**a**) AP X-ray and (**b**, **c**) CT clearly showing the fracture configuration, (**d**) treated by closed reduction and screw fixation through a small anterolateral incision

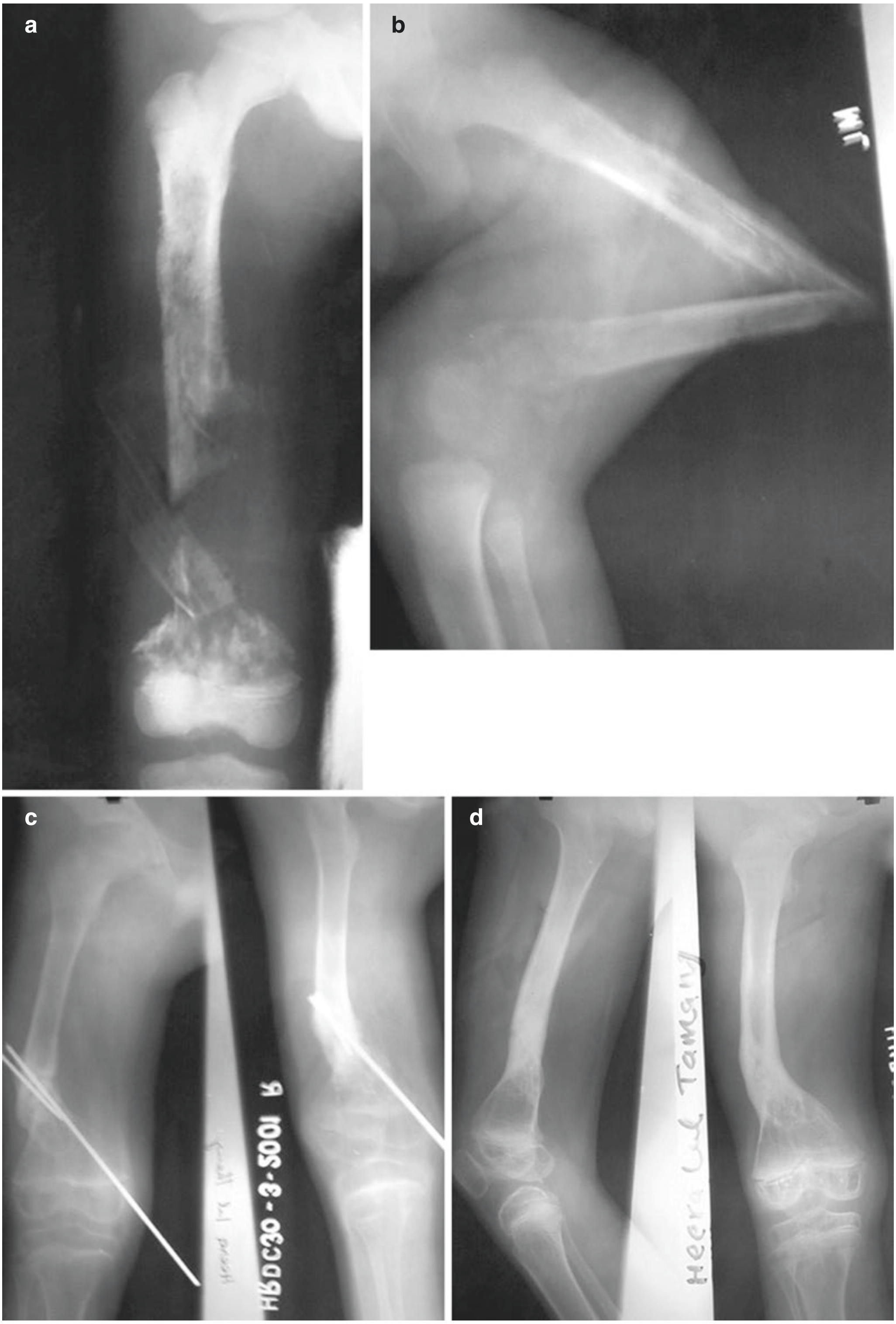

Fig. 28.14 (**a**, **b**) This pathologic open femoral shaft fracture due to osteomyelitis was (**c**) treated by debridement, antibiotics, and fixation with Kirschner wires. (**d**) The fracture healed with moderate varus and shortening, but no evidence of persistent infection

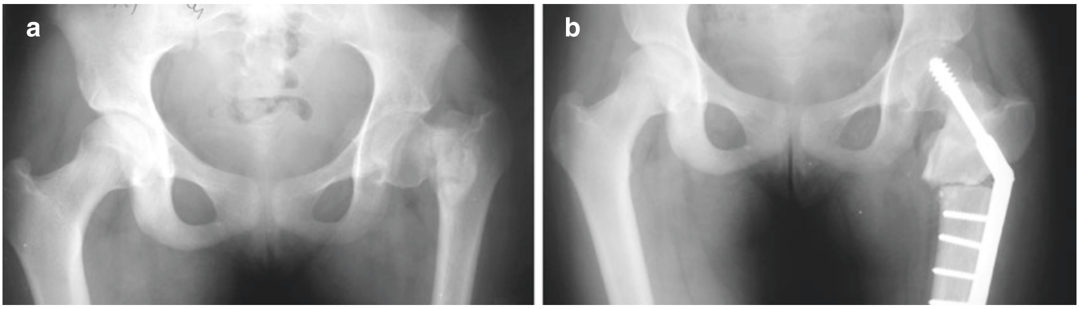

Fig. 28.15 (**a**) This neglected femoral neck fracture was (**b**) treated by a subtrochanteric valgus osteotomy

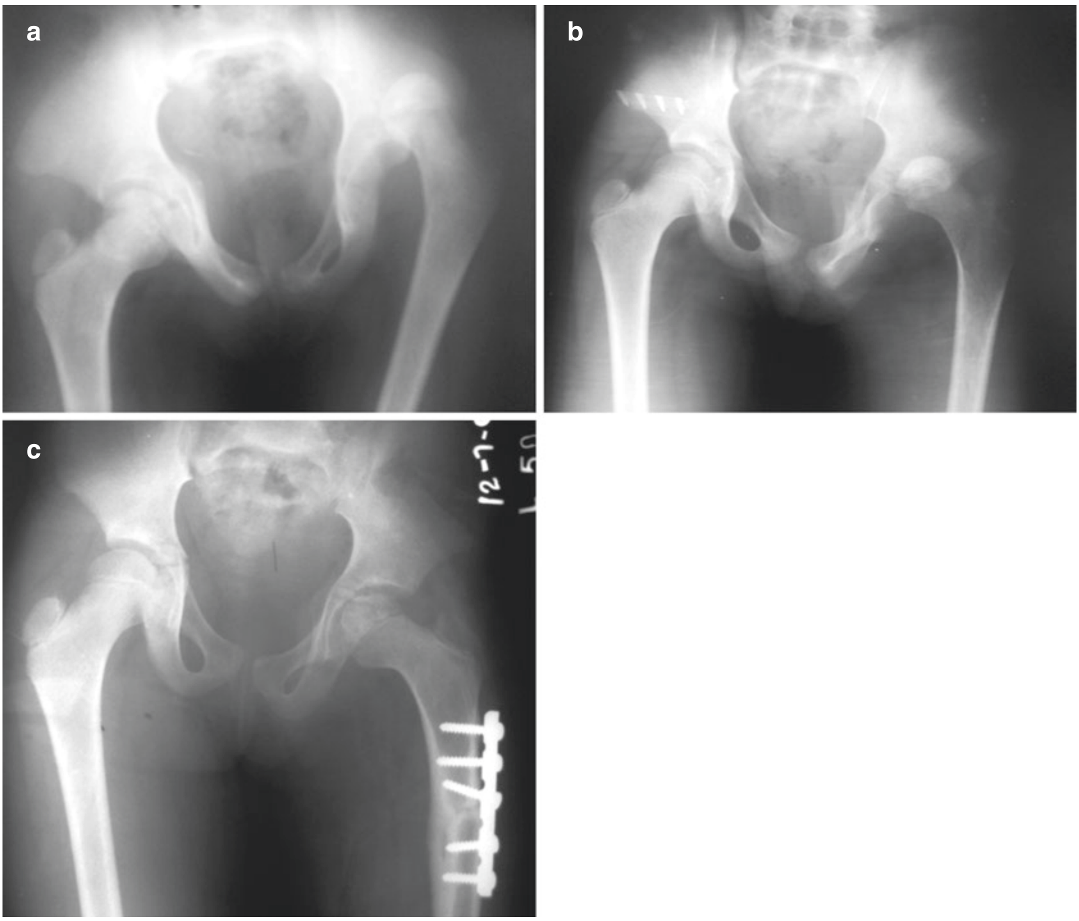

Fig. 28.16 (**a**) A neglected posterior dislocation of the hip was first treated by (**b**) skeletal traction with a distal femoral pin. (**c**) An open reduction and femoral shortening were required to reduce the joint and avoid excessive tension

coexisting fractures are infrequent. Patients present with pain, stiffness, instability, gait disturbance, and leg length discrepancy. While observation may be appropriate for the rare case in which the hip is asymptomatic and functioning well, options to achieve reduction include the "heavy traction" method or open reduction, with or without preliminary traction and/or femoral shortening. Other treatments to salvage a chronically painful, dislocated hip include excisional arthroplasty, arthrodesis, and pelvic support osteotomy (see Chap. 41).

The “heavy traction” method employs distal femoral skeletal traction with the hip abducted starting at 10% of body weight and increasing the weight as tolerated between 3 and 6 weeks until the femoral head reaches the level of the acetabulum. The hip is then adducted to achieve a concentric reduction, and a hip spica is worn for 6 weeks. Even though reduction is achieved in fewer than 50% of patients, preliminary traction stretches the soft tissues, making any operative intervention easier and less likely to cause avascular necrosis.

Open reduction of the hip can be performed via an anterior, lateral, or posterior approach, with or without preliminary skeletal traction (Fig. 28.16). A posterior approach may have a higher risk of AVN, and our experience suggests that displacement of the femoral head through the joint capsule, or “buttonholing,” is less common in children compared to adults—perhaps due to greater soft tissue laxity and the lower energy associated with many of these injuries. A shortening femoral osteotomy may be needed, depending on soft tissue tension at the time of reduction. If unstable, K-wire fixation can maintain the reduction, and a spica cast is worn for 6 weeks. The K-wire can be placed through the trochanter and into the ilium without traversing the joint; in this manner it can be removed in the outpatient clinic. This method has been successful in dislocations up to 2 years, and though AVN is common, it does not seem to affect the results at short- to midterm follow-up. A failed open reduction does not preclude any of the salvage treatment options (See Chap 30).

Acknowledgment The authors would like to acknowledge Dr. Kaye Wilkins for his lifelong dedication to improving the care of children with musculoskeletal injuries and also for his contributions to this chapter in the first edition of this book.

Additional Resources

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Dr. Kaye Wilkins has produced a number of excellent lower extremity trauma videos which are available on u tube and on the Global HELP website. https://global-help.org/videos/fractures-of-the-foot-in-children/.

(https://global-help.org/videos/fractures-of-the-proximal-metaphysis-and-shaft-of-the-tibia/;https://global-help.org/videos/fractures-of-the-region-of-the-knee-in-children/).

(https://global-help.org/videos/fractures-in-the-region-of-the-ankle-in-the-pediatric-patient/).

Part V

Musculoskeletal Infections

29 Introduction to Musculoskeletal Infections

Jacques L. D'Astous and William James Harrison

Introduction

Musculoskeletal infections are a common cause of disability in economically underdeveloped regions. Their management is challenging owing to the usual delayed or neglected mode of presentation and limitation of available resources. Plain radiographs are often the only imaging at hand, laboratory services and infectious disease consultation may be deficient, and only a limited number of antibiotics may be available. Challenges include not only eradicating the infection but also managing other orthopedic complications such as joint destruction, bone loss, pathological fracture, angular deformities, and limb length discrepancy. The importance of nutritional supplementation as an adjunct in the treatment of all infections cannot be overemphasized as patients are often malnourished at baseline, reducing the effectiveness of their immune systems.

In this chapter we outline the basic treatment principles for septic arthritis; acute, subacute, and chronic osteomyelitis; and pyomyositis. Subsequent chapters focus on specific management principles for neglected joint sepsis, chronic osteomyelitis, osteomyelitis and septic arthritis in adults, and musculoskeletal tuberculosis.

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Septic Arthritis

Septic arthritis can be caused by bacteria, mycobacteria (TB), or fungi. The etiology is most often hematogenous seeding of the synovium but can also be due to extension of a metaphyseal osteomyelitis, following surgery, or rarely from direct traumatic inoculation. Septic arthritis associated with bacterial pathogens typically evolves rapidly, while the damage associated with tuberculous arthritis progresses slowly over months to several years.

After approximately 18 months of age, the physis typically serves as an effective barrier to the spread of infection from the bone into the joint. But in those younger, a metaphyseal osteomyelitis can decompress directly into the joint in locations where the metaphysis is intraarticular, namely, the proximal humerus, the radius and femur, and the distal fibula. Multiple joint sepsis can be seen in neonates, resulting in severe joint destruction and limb length inequality.

Acutely, patients present with joint pain, especially pain with motion, fever, and often a history of other infections. Limp or refusal to bear weight is common, and pseudo-paralysis of an extremity

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is often observed in infants or younger children. Neonates and toddlers may not exhibit a febrile response and may have normal laboratory studies. A high index of suspicion is warranted, and any joints suspected of having septic arthritis should be aspirated and the specimen sent (if laboratory services are available) for a cell count and differential (WBC >50,000 in acute pyogenic infection), gram stain, aerobic and anaerobic culture and sensitivity, acid-fast bacilli, and fungal stains and cultures. Blood cultures are positive in 30–60% of cases. Delayed treatment can lead to permanent joint damage, resulting in stiffness, deformity, and long-term disability.

Bacterial septic arthritis most commonly affects the large weight-bearing joints—hip and knee. Patients with hip sepsis usually hold the hip in flexion, abduction, and external rotation to minimize intracapsular pressure. Plain radiographs may show soft tissue swelling, loss of soft tissue planes, and occasionally bony changes consistent with an adjacent osteomyelitis. Joint space widening and subluxation or dislocation of the hip can be seen in neonates or infants with hip sepsis.

Typically, an excellent result can be expected with prompt diagnosis, surgical drainage, and antibiotics. While repeated aspiration may be appropriate in concert with antibiotics in the management of smaller joint infections in certain clinical situations, in most austere environments, emergent surgical drainage is required in large weight-bearing joints, especially the hip and knee. Complications of delayed or inadequate treatment include avascular necrosis, joint ankylosis and/or degeneration, loss of motion, malpositioning of the limb, limb length inequality, and chronic pain.

Patients with joint infection due to mycobacteria or fungal sources will have a more indolent clinical course and pathological behavior similar to juvenile arthritis (see Chap. 33).

Osteomyelitis

Osteomyelitis can be caused by bacteria, mycobacteria (tuberculosis or other), fungi, or parasites. Organisms gain access to the bone through a hematogenous route in the majority of cases, especially in children. Other sources include direct inoculation by a penetrating injury or following surgery, open fracture, or local spread of disease. Osteomyelitis can be classified by duration (acute, subacute, and chronic), route of infection (hematogenous, direct), anatomic location, and age group.

Acute Hematogenous Osteomyelitis

Acute hematogenous osteomyelitis is more common in children than adults and presents with localized pain, fever, lethargy/malaise, and limp or refusal to bear weight or use a limb. The signs and symptoms of acute osteomyelitis may be similar to acute septic arthritis, making a differential diagnosis difficult. Infants can present with pseudo-paralysis of the limb, and fever may be absent. Physical findings include tenderness to palpation (especially in the metaphysis), swelling, warmth, and erythema, and often a sympathetic effusion or coexisting septic arthritis of an adjacent joint. When laboratory studies are available, the WBC count is elevated in 25–75%, except in neonates or infants where the WBC counts are often normal. C-reactive protein (CRP) becomes elevated within 6 h of infection, making it most useful for an early diagnosis. The erythrocyte sedimentation rate (ESR) becomes elevated within 24–48 h of onset.

Radiographs demonstrate soft tissue swelling and loss of soft tissue planes; however, bony changes, such as periosteal reaction and osteolysis, may not appear for 10–14 days. When the diagnosis is suspected clinically, aspirate the area of maximum tenderness with an 18- or 20-gauge needle under local anesthesia. If no purulent material is aspirated at the periosteum, the needle should be advanced through the thin metaphyseal bone. The natural history is shown in Fig. 29.1.

In hematogenous osteomyelitis, organisms typically lodge in the metaphyseal region because of sluggish blood flow in venous sinusoids adjacent to the physis. The organisms proliferate, and intramedullary pressure increases due to the host inflammatory response. The infected material breaks through the thin metaphyseal cortex, resulting in a subperiosteal abscess. This subperiosteal abscess can expand, elevate the periosteum, and deprive the cortical bone of its blood supply, resulting in bone necrosis and the development of a sequestrum or sequestrae (Fig. 29.2). The entire shaft may become sequestered. Sequestrae are less common in adults

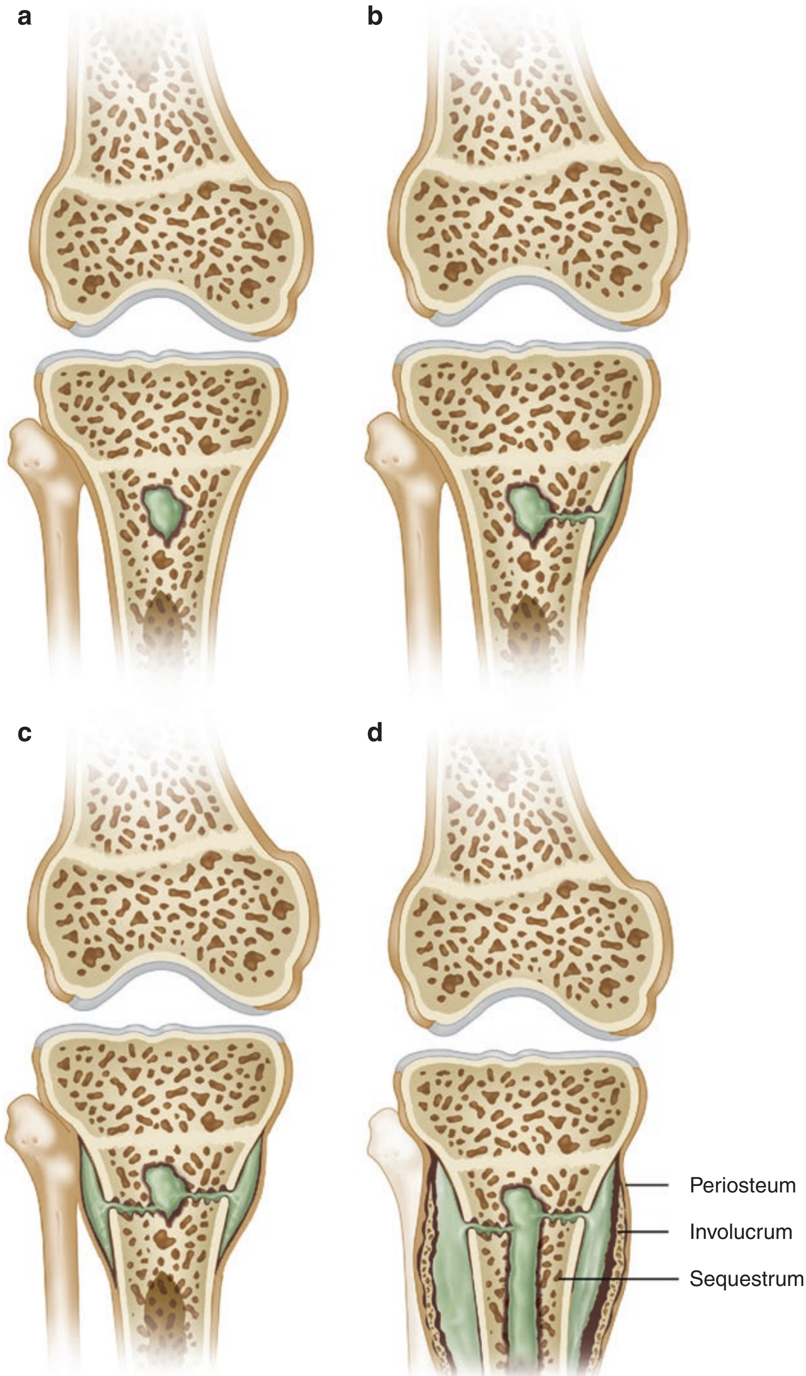

Fig. 29.1 Natural history of pediatric hematogenous osteomyelitis of the tibial metaphysis. (**a**) The infection begins in the metaphysis, forming an intraosseous abscess that (**b**) decompresses through the thin metaphyseal cortex to become a subperiosteal abscess. (**c**) The abscess elevates the periosteum, stripping the blood supply to the bone. (**d**) One or more areas of the bone become necrotic (sequestrae). The host periosteal response of new bone formation, involucrum, stabilizes the mechanical environment, partially or completely resorbs sequestrae, and reconstitutes bone loss

than in infants and children. The communication between the medullary canal and a subperiosteal abscess is called a "cloaca." Eventually, the abscess can break through the skin, forming a sinus tract. The host response, as seen in the periosteum, is an attempt to reestablish stability by new bone formation—the involucrum (Fig. 29.3). The involucrum is typically less robust in adults than it is in children. Where the metaphysis is intracapsular (proximal femur, proximal radius, proximal humerus, distal fibula), there is a risk of coexisting septic arthritis. Organisms have a number of mechanisms to evade the hosts defenses, and antibiotics, such as forming a glycocalyx, slowing their metabolism, and migrat-

Fig. 29.2 (**a**–**d**) Examples of sequestrae and involucra. (**a**, **d**) The involucra of the tibia and metatarsals are partial, weak, and poorly demarcated from the indistinct sequestrae. (**b**, **c**) The involucra are complete and robust around the well-demarcated sequestrae in the ulnar shaft and the proximal femur

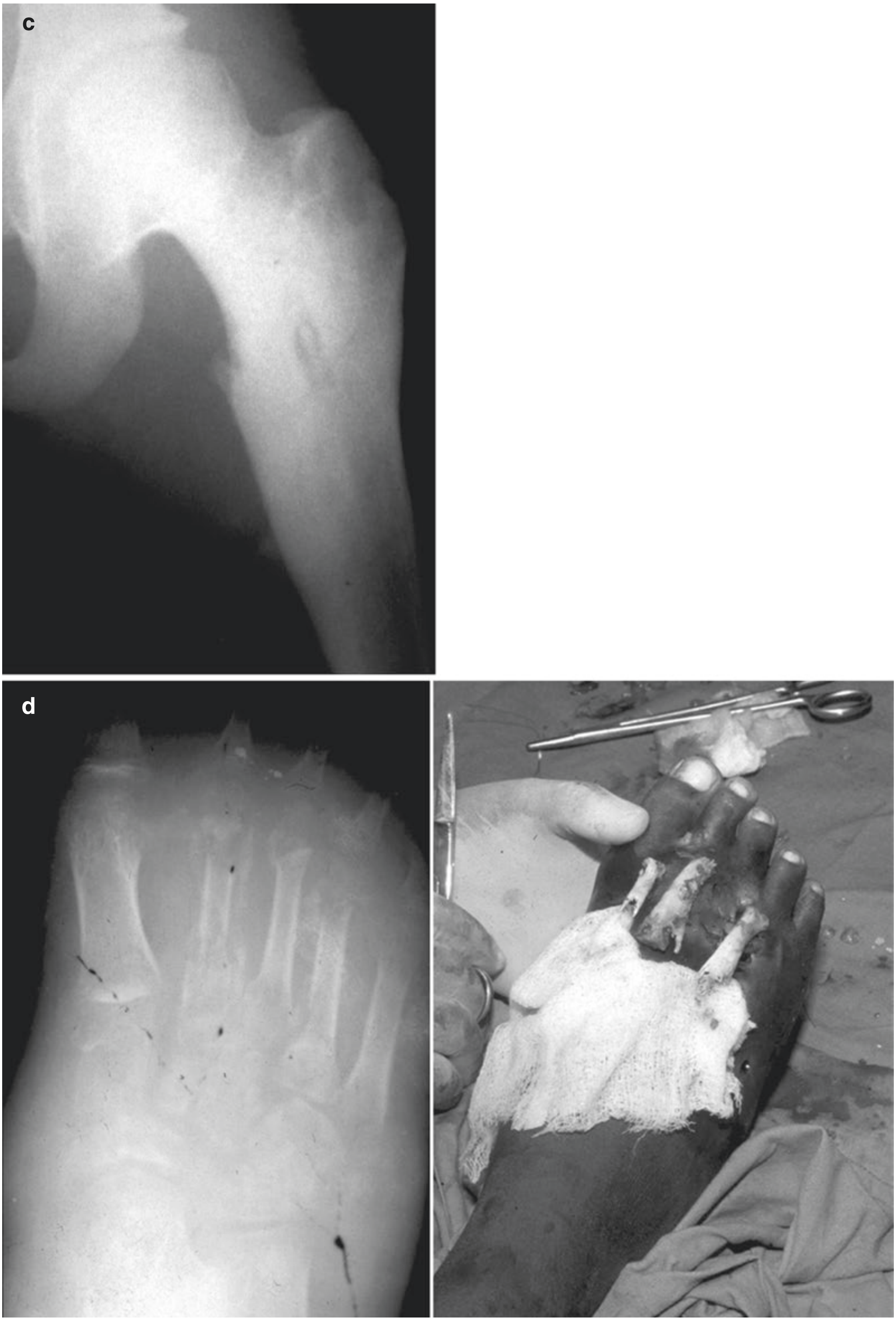

Fig. 29.2 (continued)

Fig. 29.3 The involucrum varies considerably in appearance. It may appear as a (**a**, **b**) smooth periosteal density as seen here in the midshaft of the humerus and both sides of the tibia. (**c**, **d**) As a smooth and sclerotic reaction from the addition of multiple layers of new bone in this patient with clavicular osteomyelitis and a draining sinus over the medial clavicle. (**d**) A fluffy appearance to the new bone formation as seen on both sides of the tibia, and (**e**) as a thickened, densely sclerotic reaction

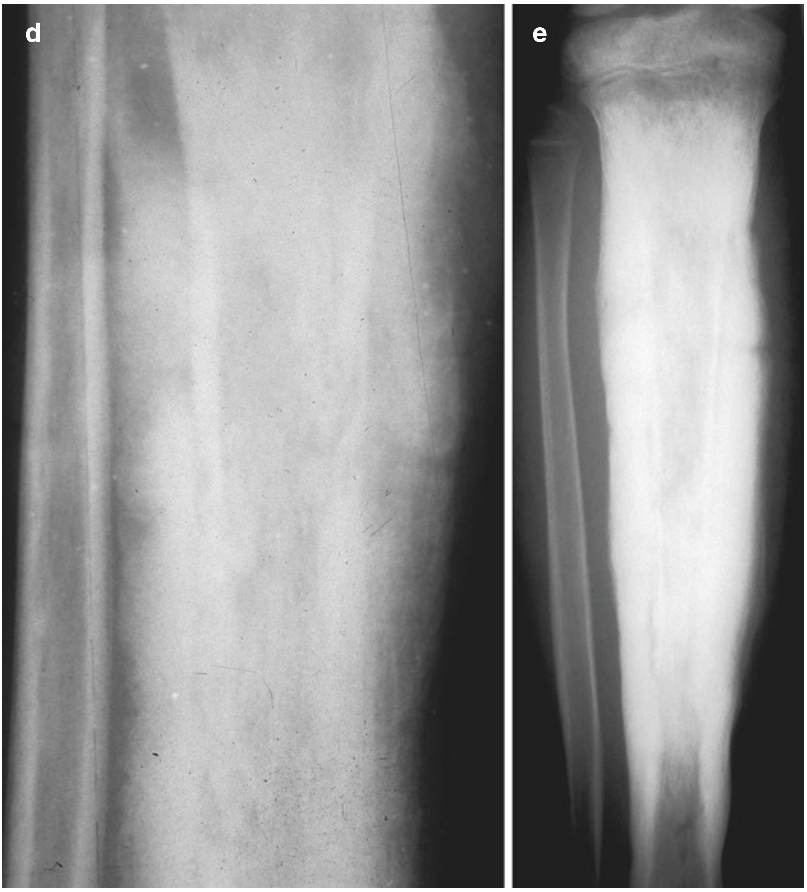

Fig. 29.3 (continued)

ing to an intracellular location. In some severe cases of infection the organisms essentially hijacks the host's inflammatory response in order to form abscesses and to disseminate through the vascular system. The evolution from an acute to a chronic disease state depends on access to treatment and whether the treatment has been successful. With early diagnosis and treatment most cases of osteomyelitis can be eradicated.

Subacute Osteomyelitis

Subacute osteomyelitis presents with intermittent bone pain, usually at night, which is often exacerbated by activity and with few or no systemic signs or symptoms. The symptoms of local discomfort to palpation or mild soft tissue swelling are often present for at least 2 weeks before the patient arrives in the clinic or OPD. This is due to the combination of an indolent organism and strong host defenses. Laboratory studies are usually normal, although inflammatory markers can be slightly elevated. Staphylococcal species are most often cultured.

The radiographic features vary from a well-circumscribed lytic metaphyseal lesion with a sclerotic rim (Brodie's abscess) that can cross the physis, to a diaphyseal lesion with an aggressive periosteal reaction. The differential diagnosis includes benign or malignant bone tumors and tuberculous osteomyelitis. A biopsy is often required to establish the diagnosis. Empiric antibiotics can be considered when characteristic x-ray features are present, such as a sclerotic rim to the lucency, a lucency that crosses physis, has a serpentine shape or multiple cavities, is epiphyseal, and is not associated with changes in the surrounding bone, and the patient has no systemic symptoms.

Chronic Osteomyelitis

The evolution from acute osteomyelitis to chronic osteomyelitis is highlighted in previous sections outlining the development of sequestrae, and the host's reaction in the form of involucra. This chronic disease state involves a persistence of dead bone and/or debris which has been incompletely resorbed and essentially represents a "standoff" between the immune system and the infectious focus or foci. Patients with chronic osteomyelitis present with a history of intermittent bone pain extending over months to years, localized tenderness, and usually a draining sinus. Foci of dead bone and/or devitalized tissue harbor microorganisms, causing intermittent episodes of infection. Some patients may have exposed bone. Other findings at presentation can include pathological fracture, limb length discrepancy, or angular deformity. Plain radiographs are sufficient for evaluation. Laboratory tests are usually normal unless active infection is present. Since neoplasia can mimic chronic infection (Fig. 29.4), a biopsy should be

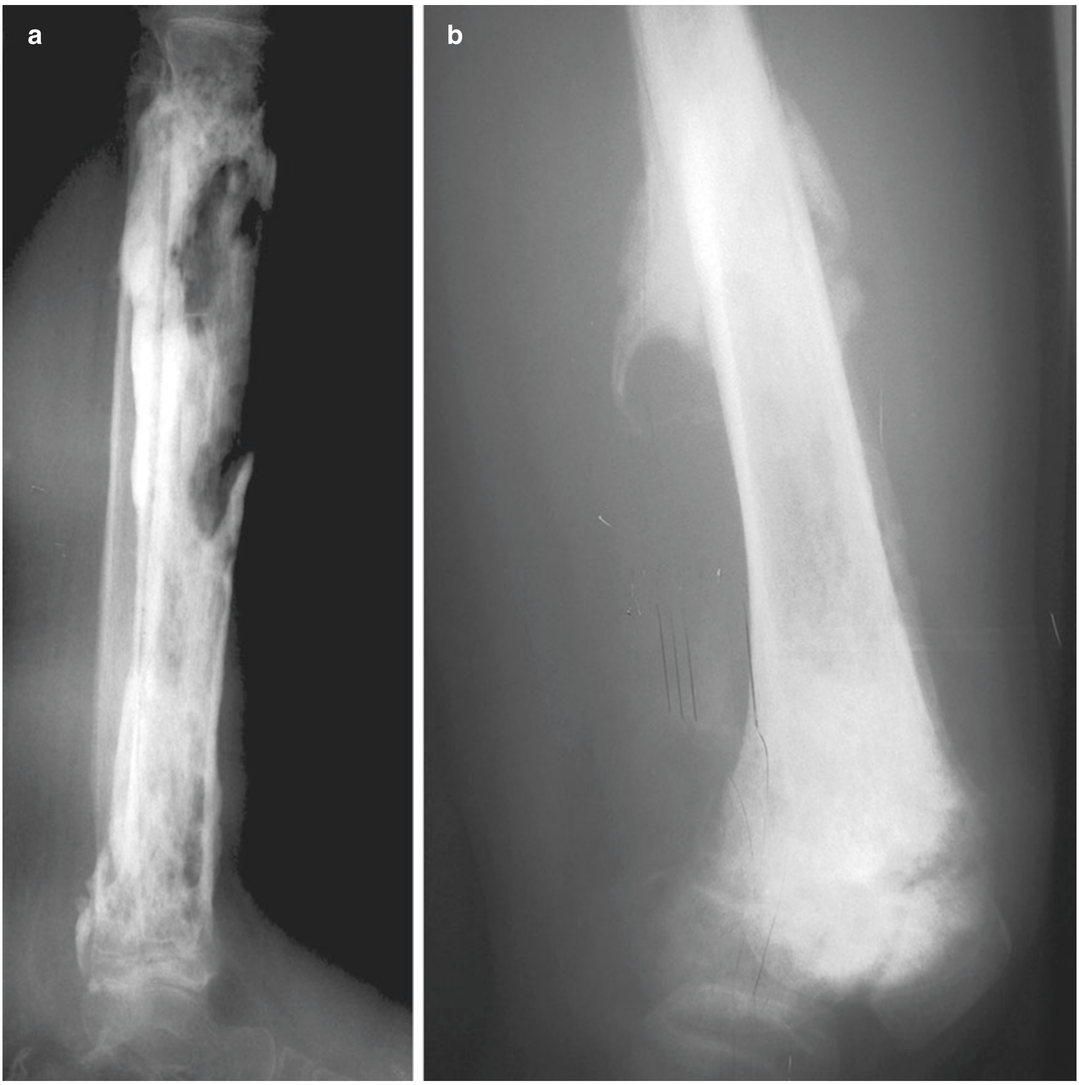

Fig. 29.4 Chronic osteomyelitis can present with radiographic findings similar to malignancy, with (**a**) extensive bone destruction with minimal host response, or (**b**) the involucrum can appear radiographically similar to a Codman's triangle

obtained in selected cases. The treatment involves removal of all infected material (similar to tumor surgery), followed by reconstruction of any bone loss and correction of any other sequelae such as angular deformity. Antibiotics are an adjunct (see Chap. 31).

Mycobacterial Musculoskeletal Infections

Mycobacterial or fungal infections can also result in septic arthritis and osteomyelitis and are most commonly observed in the setting of a compromised host, such as malnutrition, HIV/AIDS, and chronic comorbidities. These infections have a more indolent or subacute presentation than bacterial infections. The routes of infection include hematogenous seeding from a visceral source, direct inoculation, or spread from a neighboring site. Up to one third of the world's population have been exposed to *Mycobacterium tuberculosis*, and musculoskeletal manifestations (<10% of TB infections) include arthritis (45%), osteomyelitis (5%), and spondylitis (50%) (see Chap. 33).

TB mimics a host of diseases both clinically and radiographically. The differential diagnosis includes brucellosis and fungal organisms such as *Candida*, *Blastomyces dermatitidis*, *Coccidioides immitis*, *Histoplasma capsulatum*, and *Cryptococcus neoformans*. In echinococcal osteomyelitis, parasite ova ingested from contaminated vegetables or water release a larval tapeworm that invades the liver via the portal venous system and spreads to the bone via a hematogenous route. Areas most commonly involved in mycobacterial or fungal infections include the spine, pelvis, and long bones, especially the proximal femur. In the absence of advanced laboratory techniques, the diagnosis must be suspected based on local prevalence of the disease and familiarity with the unique presentation and imaging characteristics of these diagnoses. Empiric treatment is often instituted using clinical guidelines.

Pyomyositis

Pyomyositis represents a pyogenic intramuscular infection and is seen most commonly in tropical regions. The differential diagnosis includes muscle strain, hematoma, thrombophlebitis, osteomyelitis, and neoplasia. It is more common in immunocompromised patients, particularly those infected with HIV. The symptoms evolve over days to weeks, from the insidious onset of pain and swelling (invasive stage) to abscess formation and often systemic toxicity (suppurative stage). *Staphylococcus aureus* is the most common organism (80%), and antibiotics alone may suffice during the early, invasive stage. Since abscesses are subfascial, aspiration is made with a large bore needle which must be inserted deep, and it is not unusual to need more than one attempt. Ultrasound can make the procedure easier. Abscesses should be drained, and a short course of intravenous antibiotics is followed by an additional period of oral antibiotics. The overall duration of treatment should be 3–6 weeks. Tuberculosis rarely leads to intramuscular abscesses.

Suggested Reading

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30 Neglected Septic Arthritis in Children

David A. Spiegel, Ashok Kumar Banskota, and Bibek Banskota

Introduction

The initial damage to the joint in septic arthritis occurs from local products liberated by the bacteria and the host's inflammatory response. The sequelae can result in considerable disability especially when the infection occurs in a weight-bearing joint such as the hip. Treatment must be individualized and depends on whether stability or motion is the goal, as well as the resources and expertise available. While a stable and painless joint may be the goal for some joints (ankle, wrist, or knee), treatments that preserve motion are more desirable at the hip and elbow. In austere environments, salvage, rather than reconstruction, may be the better option as irreversible changes in the joint and surrounding tissues are common due to delays in presentation or complications of previous treatments that are difficult to predict and correct (Fig. 30.1a–c). Septic arthritis may also be secondary to a metaphyseal osteomyelitis in the proximal humerus, proximal radius, proximal femur, or distal fibula, as these metaphyses are intra-articular, making these infections more difficult to diagnose and treat.

This section illustrates the principles as applied to the sequelae of septic arthritis of the hip. While many of the strategies described are technically demanding and require specialized training, experience, and equipment, most are commonly performed at the tertiary level in resource poor settings, and a visiting surgeon must assess whether his or her training and experiences are sufficient to tackle these challenging cases. While the long-term outcomes following these salvage procedures have not been well defined, the goals are to provide symptomatic relief and functional improvement and to delay or eliminate the need for interventions such as total joint arthroplasty.

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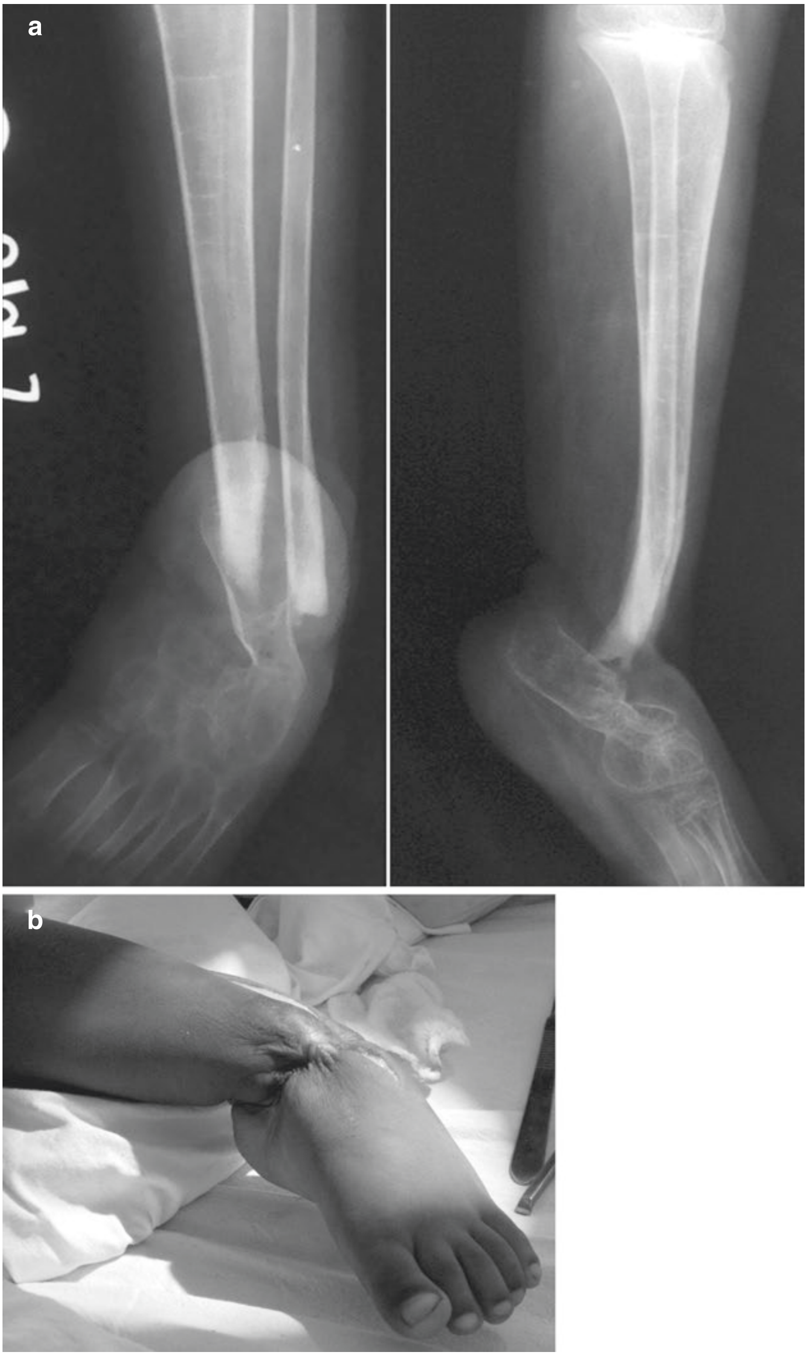

Fig. 30.1 (**a**) X-rays and (**b**) appearance of a child who presented with the residua of ankle septic arthritis and osteomyelitis. (**c**) A plantigrade foot was salvaged by fusing the distal tibia and fibula to the calcaneus, recognizing that limb lengthening would be required at a later date to treat leg length discrepancy

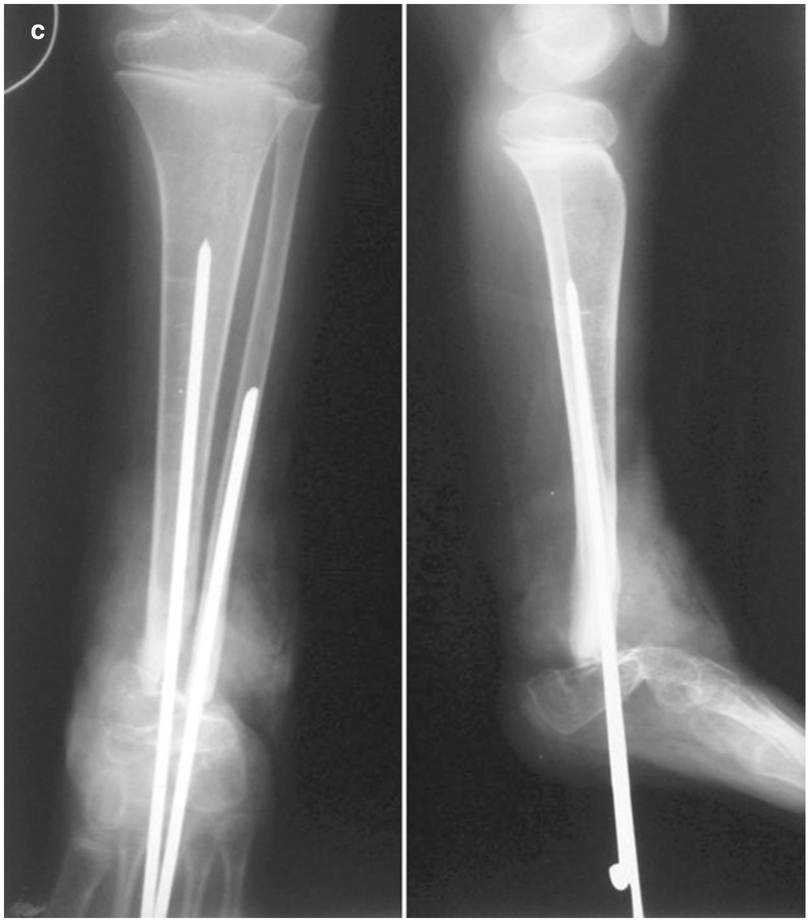

Fig. 30.1 (continued)

Sequelae of Hip Sepsis

The sequelae of hip sepsis include a wide range of morphologic abnormalities of the proximal femur. Secondary changes in the acetabulum can also occur, either as a result of the infection or in response to altered anatomy of the proximal femur. In addition to direct damage to the articular cartilage and the effects of the host's inflammatory response, increased intra-capsular pressure may result in avascular necrosis. Growth distrubance may also result in altered proximal femoral anatomy. The risk of a poor outcome is increased if diagnosis and treatment are delayed and if coexisting proximal femoral osteomyelitis is present. Growth disturbances of the femoral head or neck, such as coxa magna (Fig. 30.2a–d), femoral neck pseudoarthrosis (Fig. 30.3a, b), septic dislocation with the femoral head present or absent, or post-septic fusion (Fig. 30.4a–e), may also occur. In infants up to 18 months of age, transphyseal vessels allow metaphyseal osteomyelitis to extend to the epiphysis and the joint explaining some of the head and neck changes. Clinical findings may include pain, instability during ambulation, leg length discrepancy, and loss of motion.

The history focuses on the impact of symptoms on activities of daily living, particularly the presence, location, and intensity of pain, and the activities or positions that precipitate or relieve it.

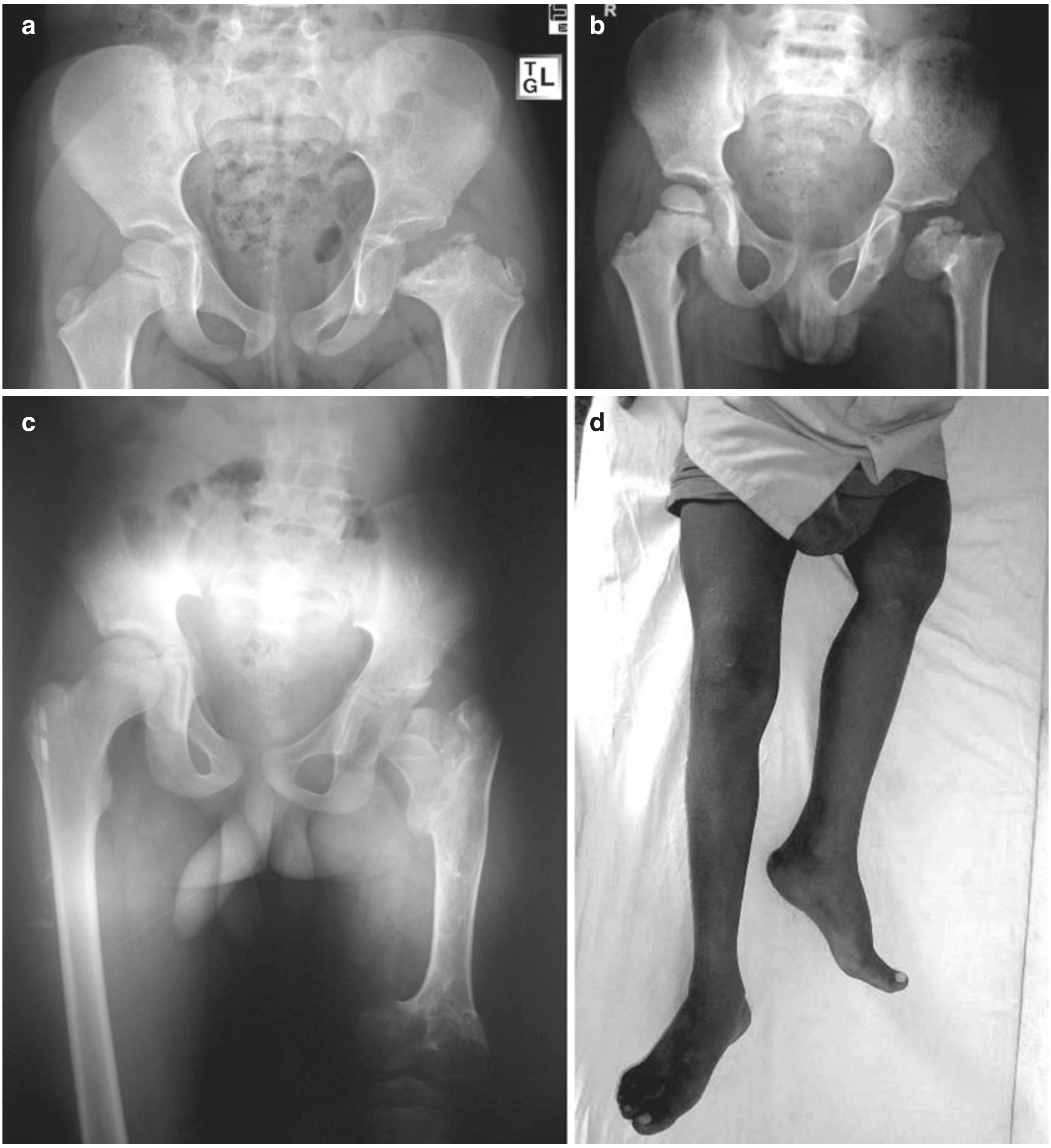

Fig. 30.2 Sequelae of hip sepsis. (**a**, **b**) In addition to proximal femoral varus or valgus deformities and rotational deformities, coxa magna is commonly observed due to hyperemia or AVN, while coxa breva is due to altered growth of the femoral neck. (**c**) Septic arthritis can be associated with proximal femoral osteomyelitis. (**d**) Multiple joint sepsis often results in significant limb shortening and joint abnormalities

The source of pain may be intra-articular from damage to the articular cartilage or impingement or extra-articular due to soft tissue contracture or abductor insufficiency. The physical examination focuses on range of motion, limb alignment and length, and presence of pain when the hip is placed in certain positions. Plain radiographs may be the only imaging available, though arthrography or direct surgical inspection may be required to delineate the status of articular cartilage and the relationship between the proximal femur and the acetabulum (Fig. 30.5a–b).

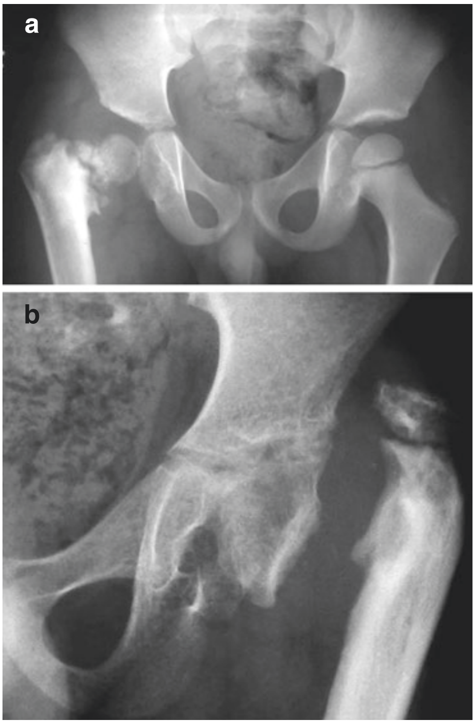

Fig. 30.3 (**a**, **b**) Pseudoarthrosis of the femoral neck

Treatment

Treatment goals are to relieve pain, improve the absolute range of motion or the functional arc of motion, improve abductor mechanics, restore stability, and correct leg length discrepancy. Treatment must be individualized, focusing on symptoms, physical findings, and the pathoanatomic changes in the femoral head and acetabulum.

The classification presented by Forlin et al. is simple and practical and helps plan treatment [1]. The scheme focuses on (1) stability and (2) the degree of destruction of the proximal femur. The four categories are:

- *IA* Femoral head present and reduced
- *IB* Femoral head/neck absent but remaining proximal femur has not migrated superiorly (Fig. 30.4b)
- *IIA* Femoral head present but dislocated (Fig. 30.4a)
- *IIB* Femoral head/neck absent and remaining proximal femur is dislocated or superiorly migrated (Fig. 30.4c)

Forlin et al. identified a better prognosis for hips that were reduced than for hips that were dislocated, whether or not the femoral head was present. Arthrographyms, ultrasound, and CT (with 3-D reconstruction) can each provide valuable information about the shape of the femoral head and its relationship with the acetabulum and, in turn, stability.

For cases in which the *femoral head is present and the hip is reduced* (Forlin IA), treatments include femoral osteotomies to correct abnormalities in the neck-shaft angle (coxa vara or valga) and/or rotational abnormalities (anteversion or retroversion). Pelvic osteotomies such as Salter, Dega, or Shelf can be used alone or with a femoral procedure to improve coverage. For patients with inadequate abductor mechanics, distal transfer of the greater trochanter may improve abductor function Al-Tayebi studied a number of cases using three dimensional computed tomography and identified a variety morphologic alterations of the femoral head and neck [2]. He recommended osteochondroplasty via a modified anterior iliofemoral approach to address this spectrum of abnormalities [2].

Infants and toddlers in whom the *femoral head is present but the hip is dislocated* (Forlin IIA) are treated by an exam under anesthesia and an attempt at closed reduction and spica casting. An intraoperative arthrogram may be useful. If a closed reduction is unsuccessful, an open reduction with or without a shortening varus femoral osteotomy and/or pelvic osteotomy is required. Johari et al. found that closed reduction and percutaneous adductor tenotomy were only successful in 9/21 patients, and the remaining patients required a variety of procedures to reduce the hip [3]. Factors associated with poor results included preoperative stiffness, avascular necrosis, and premature fusion of the triradiate cartilage. The authors suggested closed reduction be attempted for all patients under 2 years, with open surgical treatment for those who fail closed reduction or are older than 2 years.

In Forlin IB patients, *femoral head/neck absent but remaining proximal femur has not migrated proximally*, consider an open reduction and capsulorrhaphy to keep any residual femoral neck reduced in the acetabulum, along with a femoral and/or pelvic osteotomy as needed to enhance stability, recognizing that additional

Fig. 30.4 A spectrum of abnormalities may complicate septic arthritis of the hip and its treatment, including (**a**) septic dislocation, (**b**) destruction of the femoral head with a segment of the femoral neck articulating with the acetabulum, (**c**) loss of the femoral head and neck without proximal migration, (**d**) destruction of the head and neck with proximal migration, and (**e**) spontaneous fusion

procedures will likely be required. A modified anterior iliofemoral approach facilitates exposure for any additional interventions such as joint debridement, osteochondroplasty, capsulorrhaphy, and femoral or pelvic osteotomy.

Treatment when *the femoral head and neck are absent* with proximal migration of the residual femur (Forlin IIB) depends on the age of the patient and whether restoration of stability, limb alignment, or lengthening is the goal. For asymp-

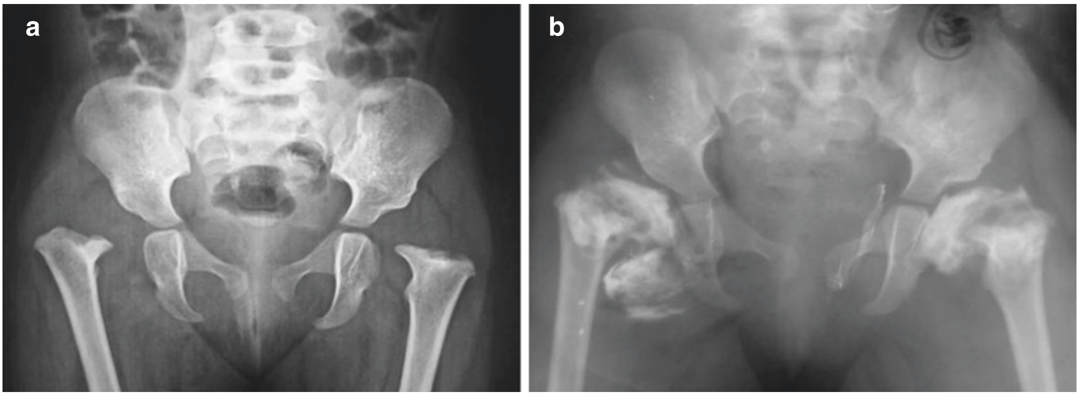

Fig. 30.5 (**a**, **b**) Arthrography is an excellent way to visualize the anatomy of the proximal femur and acetabulum. In this case there is subluxation with interposed material in the acetabulum, with flattening or an oblong shape to the femoral head. (Courtesy of Premal Naik)

tomatic patients options include observation and management of leg length discrepancy with a shoe lift or epiphysiodesis on the opposite side. Symptomatic patients may benefit from greater trochanteric arthroplasty, pelvic support osteotomy, or arthrodesis. The first two are motion-sparing techniques, recognizing that arthrodesis may be undesirable in cultures where hip mobility is required for activities of daily living. Rarely is a total hip arthroplasty available, affordable, or reasonable in adolescents and young adults.

Trochanteric arthroplasty involves debridement of any neck remnants or fibrous tissue in the acetabulum by an iliofemoral approach. The trochanteric apophysis is placed into the acetabulum, and the gluteus medius is advanced and sutured to the lateral aspect of the femur. A varus subtrochanteric osteotomy of the proximal femur may facilitate placing the trochanter into the acetabulum, but there is a risk of nonunion if extensive soft tissue dissection compromises proximal femoral blood supply. An adductor tenotomy or psoas release may be needed to restore motion. Trochanteric arthroplasty can be considered for the infant or young child who is symptomatic and in whom a pelvic support procedure is contraindicated because of rapid loss of correction due to remodeling. Variations of greater trochanteric arthroplasty include a modified Harmon arthroplasty described by Choi et al. [4] and the modified Albee arthroplasty described by Li et al. [5], in which the medial portion of the greater trochanter is angulated into varus via an incomplete osteotomy to reduce the trochanteric cartilage into the acetabulum. A triangular iliac crest graft is wedged into the osteotomy to maintain correction (Fig. 30.6a–e). While the long-term prognosis for trochanteric arthroplasty is guarded, the goal is to relieve symptoms, improve gait mechanics, and delay or eliminate the need for other reconstructive options.

Pelvic support osteotomy, also referred to as the Ilizarov hip reconstruction, addresses ambulatory instability (pistoning), leg length discrepancy, and abnormalities in limb alignment. Most studies have concerned skeletally mature young adults with a variety of diagnoses (hip sepsis, DDH, polio) and have reported significant improvements in pain relief, range of motion, leg length equalization, and gait. Studies in children are limited, and remodeling can be expected, making repeat procedures necessary.

While a detailed analysis of the preoperative assessment and the surgical technique are beyond the scope of this chapter, pelvic support is provided by a proximal femoral valgus osteotomy that positions the upper femoral shaft underneath the pelvis. Preoperative standing AP radiographs of both lower extremities and an AP in maximum adduction allow assessment of limb alignment and lengths. Some authors also use a view in which the patient stands with all his weight on the affected limb—“pelvic drop view” or “Trendelenburg” view. The location of the proxi-

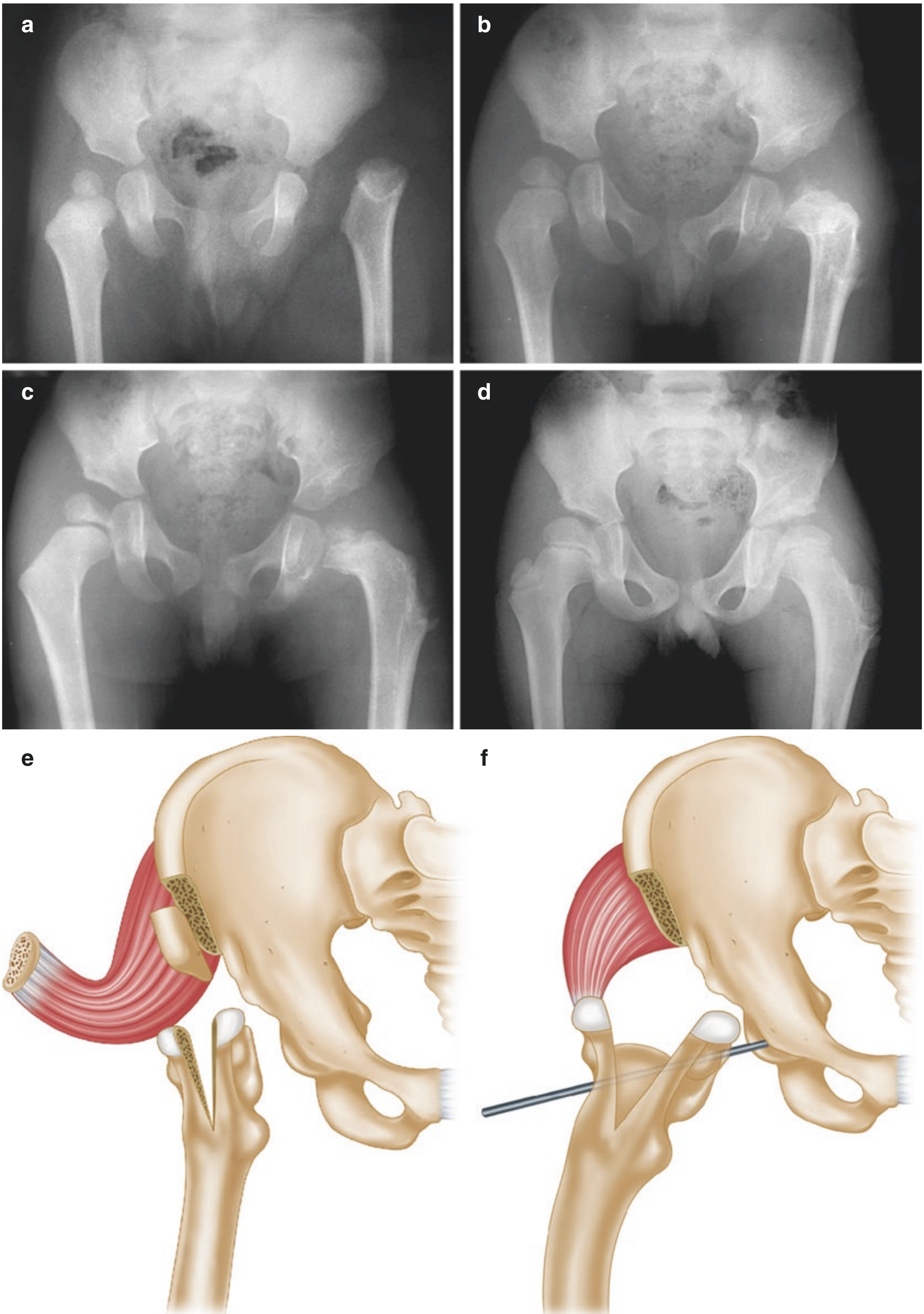

Fig. 30.6 (**a**–**d**) Greater trochanteric arthroplasty. (Reprinted with permission from Wang et al. [12] (**e**, **f**). The modified Albee arthroplasty involves placing a segment of the trochanter into the acetabulum by splitting the proximal femur vertically and inserting a wedge graft. (Reprinted with permission from Li et al. [5])

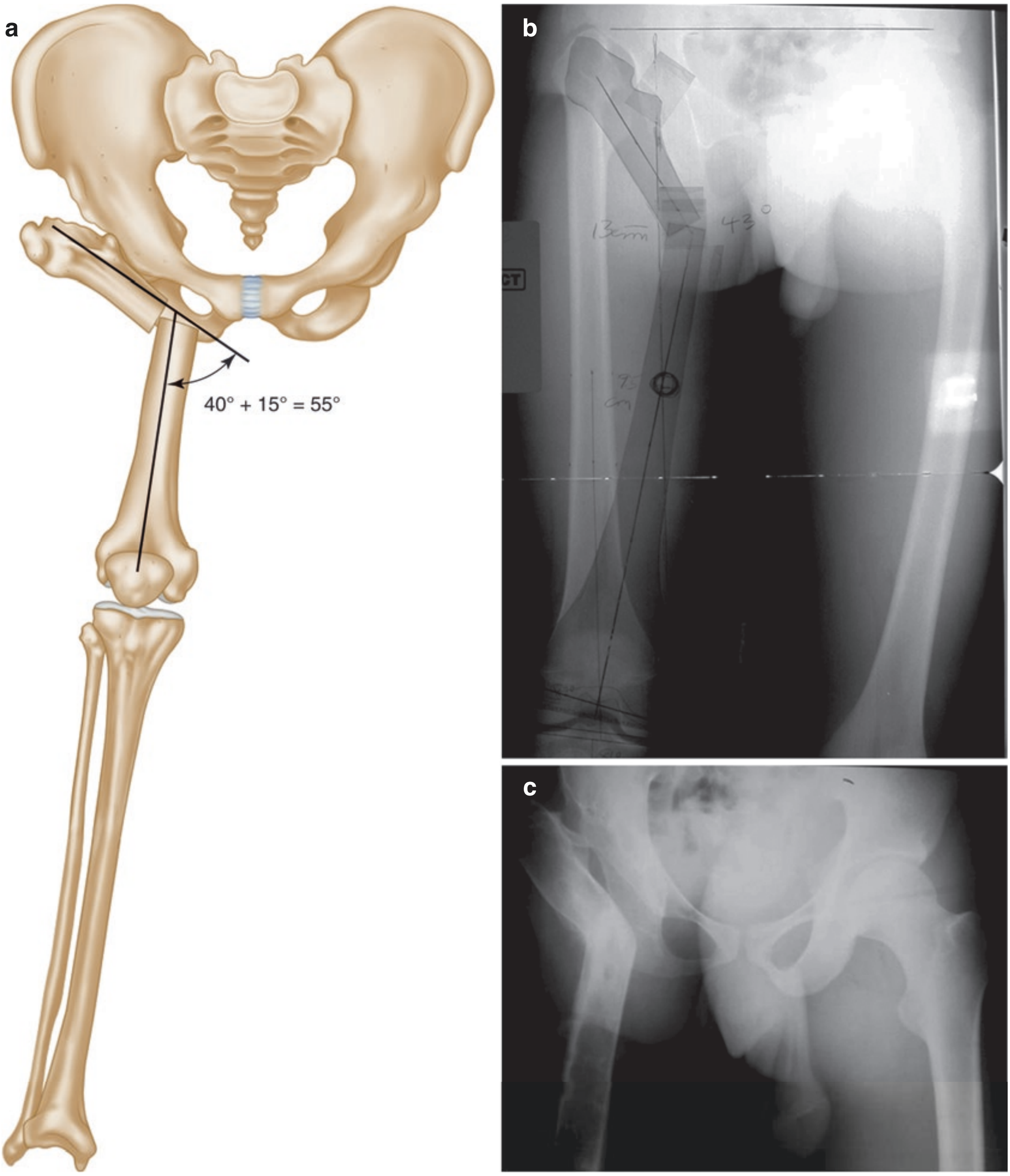

Fig. 30.7 (**a**) A maximum adduction view is important in preoperative planning for the proximal osteotomy. (Reprinted with permission from Paley [6], Fig. 19.21e), and (**b**) preoperative templating may help as well. (**c**) The proximal valgus osteotomy after healing; note that the distal osteotomy is not shown in this image. (Case courtesy of J. Norgrove Penny, M.D.)

mal femoral valgus osteotomy is determined on the maximum adduction x-ray view as the point of intersection between the femoral shaft and the ischium. The degree of adduction is calculated on a maximum adduction view, adding approximately 15° to ensure slight overcorrection (Fig. 30.7a–c). It is also important to achieve 5° of extension at the osteotomy.

Limb alignment and length are restored through a second, more distal osteotomy

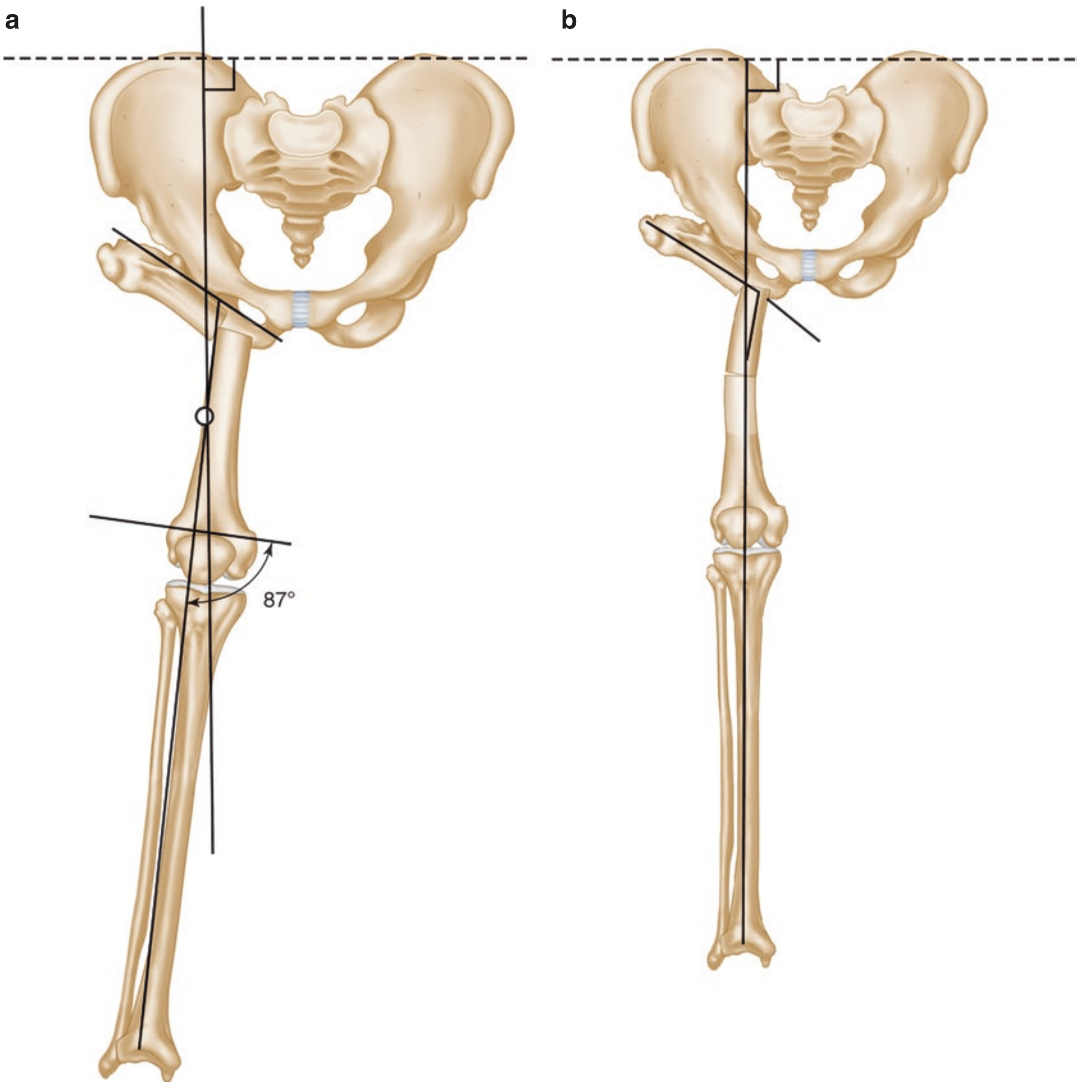

Fig. 30.8 The distal osteotomy (**a**) is performed in the femoral diaphysis at the junction of vertical line perpendicular to the pelvis and through the apex of the proximal osteotomy and the tibial mechanical axis (denoted as the small circle in this figure) and (**b**) allows realignment of the mechanical axis and equalization of limb lengths. (Reprinted with permission from Paley [6], Figs. 19.21f–g)

(Fig. 30.8a, b). Some internal rotation may be required based on the anticipation that the valgus will externally rotate the limb. Stabilization of the osteotomies is most often by a ring, monolateral, or hybrid frame (Fig. 30.9a–c) or a combination of proximal plate and distal frame for lengthening. An option to treat bilateral septic sequelae is to realign the lower limbs relative to the pelvis (Fig. 30.10a–c).

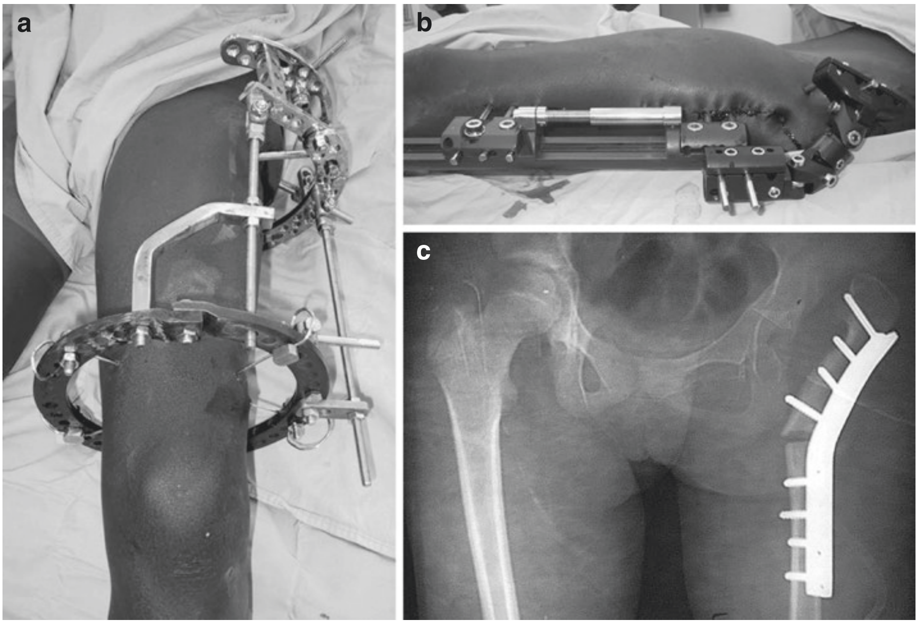

Fig. 30.9 Fixation can be achieved with a (**a**) ring construct, (**b**) hybrid or monolateral fixator construct, or (**c**) a plate for the proximal osteotomy and then a fixator for the distal osteotomy and lengthening. (Case courtesy of J. Norgrove Penny, M.D.)

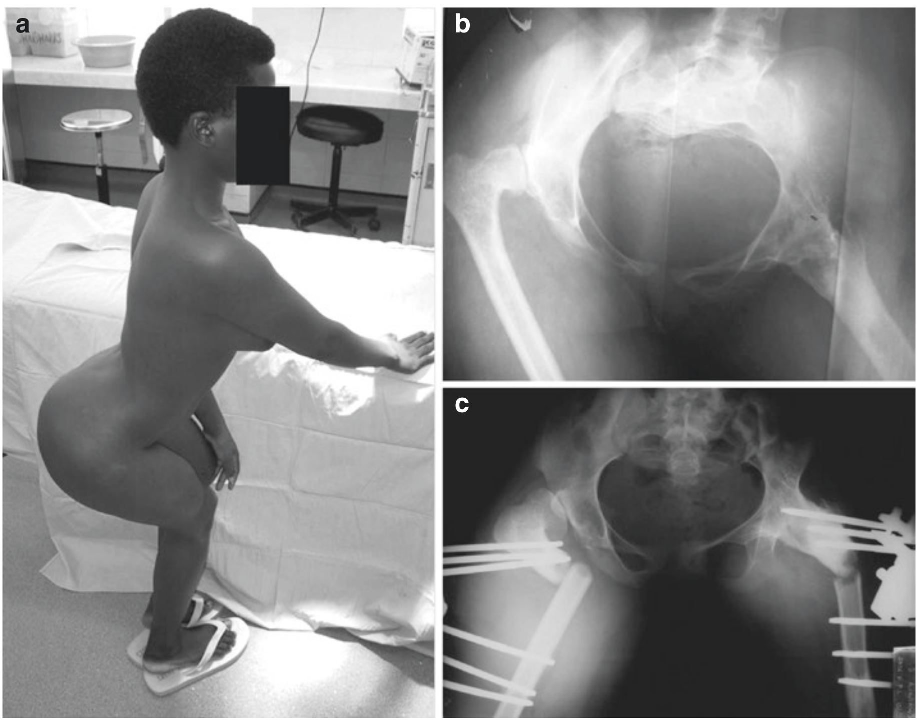

Fig. 30.10 (**a**) Appearance of a young woman with post-septic flexion/adduction contracture of the right hip and fusion on the left hip with flexion/abduction deformity. Notice the compensatory lumbar hyperlordosis. (**b**) AP pelvis x-ray. (**c**) After discussing numerous options, the patient elected to have both limbs realigned relative to the pelvis by osteotomy and external fixation. (Case courtesy of J. Norgrove Penny, M.D.)

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31 Chronic Osteomyelitis in Children

J. Norgrove Penny and David A. Spiegel

Introduction

Children with bacterial chronic osteomyelitis typically present at advanced stages in austere environments, making treatment complex, lengthy, and less likely to achieve eradication of infection and adequate return of function. However, childrens' capacity to repair and remodel diseased bone, especially with an intact periosteum, makes them candidates for all efforts to treat this disabling condition. Acute osteomyelitis evolves into a chronic state of infection in which there is persistent devitalized bone and/or debris. The definition of when an acute infection becomes "chronic" is somewhat arbitrary, as reflected in the classification system and treatment options.

The patient's general medical status is of crucial importance when assessing the chances for cure. Chronic infection results in a catabolic state, exacerbating long-standing medical conditions such as HIV/AIDS, sickle cell disease, and malnutrition, which in turn compromise host immunity. These coexisting problems predispose patients to opportunistic infections such as malaria and tuberculosis, allowing both bacterial and tubercular osteomyelitis to occur in the same patient. Nutritional, vitamin, and mineral supplements are important adjuvants because malnutrition can severely affect the immune system and be viewed as a type of reversible AIDS. Multifocal chronic osteomyelitis represents an extreme case in which host immunity is severely compromised. The infection frequently involves multiple and/or unusual sites, such as the scapula, clavicle, ribs, or the small bones of the feet and hands.

Tuberculous osteomyelitis can mimic subacute or chronic bacterial osteomyelitis, necessitating the inclusion of TB in the differential diagnosis and warranting a biopsy, especially in unresolved cases after proper surgical debridement. (See Chap. 33) The bony changes in sickle cell disease are characteristically symmetrical, involving the central diaphyses of long bones, and with a higher incidence of salmonella infection. The reason for this is unclear but may be due to otherwise innocuous salmonella having an affinity for the infarcted bone from previous sickle cell crises or from microinfarcts in the intestinal wall, allowing bacterial seeding. Neoplasia also needs to be in the differential.

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Initially, the intramedullary acute bacterial abscess decompresses through the thin metaphyseal cortex, leading to a subperiosteal abscess. With both the endosteal and subperiosteal blood supplies compromised, one or more areas of the diseased metaphysis and/or diaphysis become necrotic, forming a sequestrum or multiple sequestrae. When the infection drains through the skin, the systemic signs subside, and if inadequately treated, the infection becomes localized, encapsulated, and chronic. In general, the pediatric periosteum is resistant to infection, and its natural response is to expel the dead bone and lay down appositional new bone, known as involucrum. Sequestrae may be partially or completely resorbed by the host response.

In the chronic stage of osteomyelitis, the infection is walled off, and antibiotics cannot penetrate the tissues, making them ineffective alone in eradicating the infection. However, they may be indicated in patients presenting with systemic symptoms and used briefly to cover the surgical phase and to temporarily relieve local pain, swelling, and drainage, allowing easier surgical resection. Experience in Africa has shown that antibiotics are seldom necessary at the time of surgery or in the postoperative recovery in order to obtain a cure or good result.

Malaria treatment and prophylaxis are important in malarial endemic regions. Subclinical malaria exacerbates anemia and malnutrition and flares with the stress of surgery. A high postoperative fever in endemic locations is more likely an exacerbation of malaria than an exacerbation of osteomyelitis. If drainage recurs, think of missed loculated or hidden sequestrae.

Treatment

The goals of treatment are to eradicate the infection and treat the accompanying complications. The primary and most important treatment for children with chronic osteomyelitis is surgery. It speeds healing and minimizes the risk of progressive bony destruction by removing necrotic tissue. Antibiotics in isolation are of no value. Hematogenous osteomyelitis in children is a much different disease than osteomyelitis in adults, with a much better prognosis and the potential for cure. Active young periosteum is capable of forming new bone (involucrum), resorbing dead bone, and reconstituting long segments of diaphyseal bone under the right circumstances.

Surgery involves a stepwise approach:

- Pre-op planning—establish the correct diagnosis using a radiologic classification system that defines the natural history and assists in surgical planning.
- Adequate debridement to remove all infected material.
- Control of bleeding.
- Dead space management.
- Rehabilitation and treatment of complications.

Pre-op Considerations

The spectrum of patho-anatomic radiographic features described in the Penny [1] classification is related to the extent of bone necrosis and the host's response to the infection allowing the surgeon to:

- Judge the stability of the involved bony segment.
- Determine the timing and extent of the proposed surgery.
- Predict possible complications and/or the need for further procedures (Table 31.1).

X-rays of a *typical presentation* show a well-defined sequestrum and an adequate involucrum with structural integrity bridging the sequestrum (Fig. 31.1). The treatment involves surgical removal of the sequestrum or sequestrae at the appropriate time. In the authors' experience, about one-third of chronic osteomyelitis cases present in this manner.

Table 31.1 Penny classification for pediatric chronic osteomyelitis

Description		Treatment
I. Typical	Sequestrum and involucrum	Remove sequestrum
II. Atrophic	Inadequate involucrum which does not bridge the sequestrum	Stabilize and observe for 3–6 months; if no involucrum, then sequestrectomy; graft or bone transport
III. Sclerotic	Fusiform, dense cortical thickening, medullary canal may be obliterated, sequestrum may be hidden	Search for sequestrae, overexpose x-ray to visualize. May be difficult to remove cortical window
IV. Cortical	Localized sequestrum in cortex	Remove sequestrum
V. Walled-off solitary or multiple abscesses	Partial resorption of sequestrae, leaving well-defined lucencies in involucrum of various sizes	Look for sequestrae. If large can saucerize; if many and difficult to remove, consider antibiotics and observation
VI. Metaphyseal	Single or multiple abscesses with sclerotic margin only in metaphysis	Saucerization and curettage

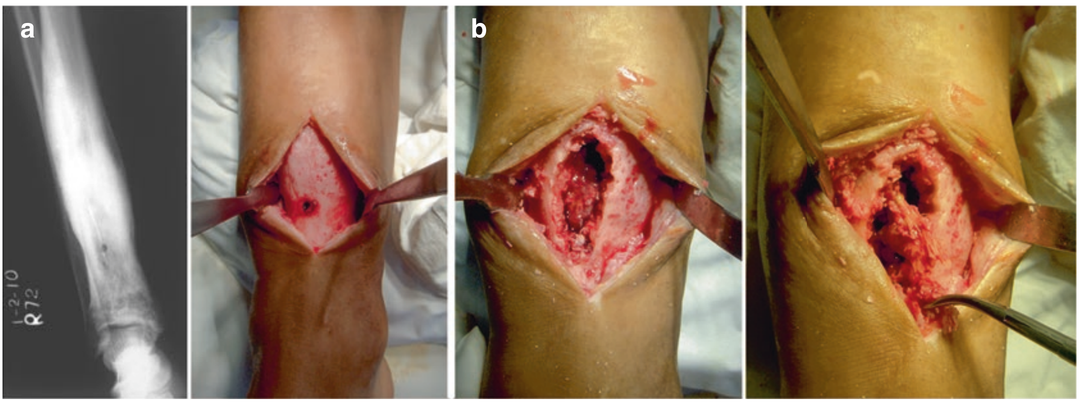

Fig. 31.1 Stages of sequestrectomy. (**a**) A sequestrum is identified distal to a sclerotic region, with a draining sinus. (**b**) An oval window facilitates sequestrectomy and debridement

In an *atrophic presentation*, one or more sequestrae may be identified; however, there is inadequate involucrum. The sequestrum can extravasate spontaneously, leaving either focal bone loss or a large, segmental bone defect. The remaining bone is usually unstable, making more complex treatments likely (Fig. 31.2). About one-third of cases present as atrophic osteomyelitis.

Sclerotic presentation (Fig. 31.3) shows a robust vascular response with the sequestrum becoming encased in bone. It may be partially or completely resorbed. Three possible scenarios result: (1) fusiform, hypertrophic appositional growth occurs, resembling the "onion skin" periosteal reaction seen in Ewing sarcoma; (2) the periosteal reaction is so prolific that the medullary canal is obliterated; and (3) the diaphysis of the bone becomes densely sclerotic. Overpenetration of the radiograph may help define small sequestrae within the sclerotic bone. Overgrowth of the involved bone and angular deformities are common from the chronic hyperemia.

Cortical presentation (Fig. 31.4) is rare and represents a milder form of disease with isolated segmental cortical death that may become walled off as a sequestrum entirely within the cortical bone.

In *walled-off solitary or multiple abscess presentation* (Fig. 31.5), the periosteal reaction is robust but not to the degree seen in the

Fig. 31.2 Atrophic Type (**a**) This patient sequestered most of the radius (**b**) sequestrum protruding through the skin. (**c**) Forearm length was maintained after sequestrectomy with an external fixator. (**d**, **e**) Once sepsis was controlled, a single bone forearm was made. (**f**, **g**) Elbow flexion and extension were full, although forearm rotation was lost

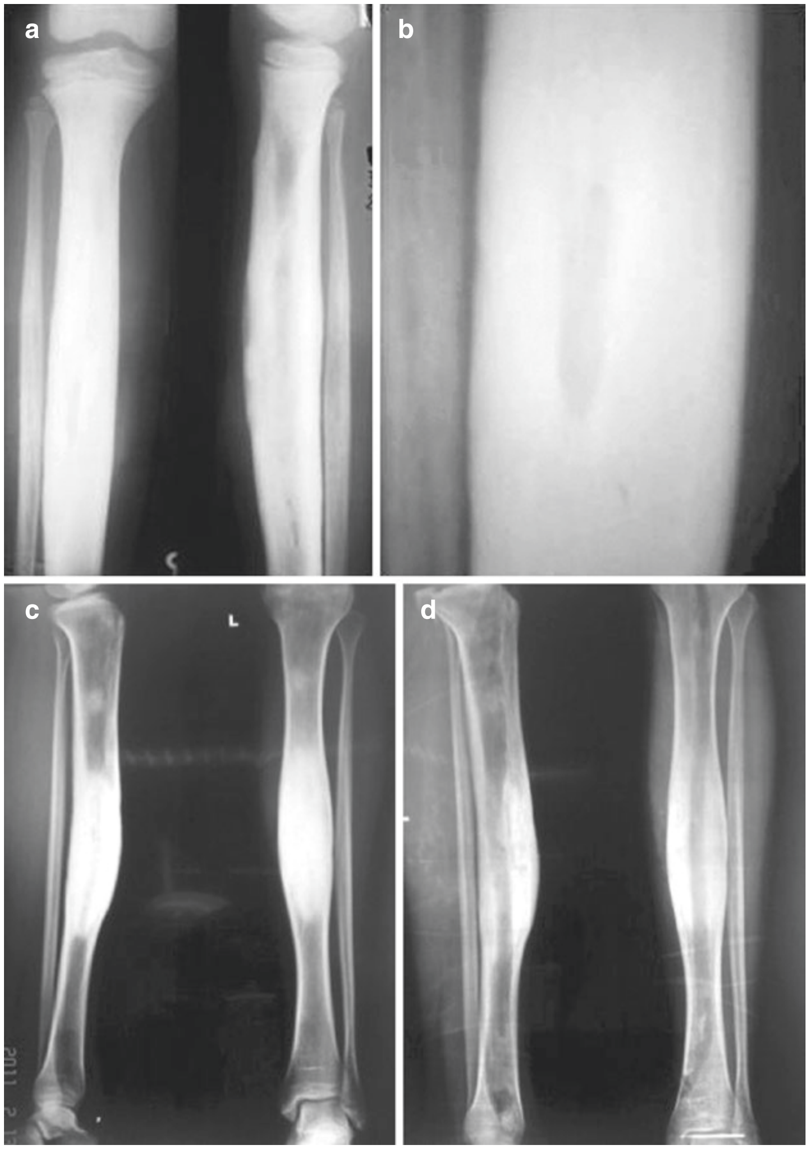

Fig. 31.3 (**a**) The sclerotic presentation exhibits a thick, dense involucrum. (**b**) Sequestrae may be difficult to appreciate on plain radiographs when the involucrum is as well developed, as in this image. Over-penetrated views or a CT scan can help identify the sequestrae. (**c**, **d**) In cases where no discreet sequestrum are identified, and when technically possible, (**d**) diaphyseal reaming can be considered to decompress the medullary canal

sclerotic presentation. A strong involucrum is formed with solitary or multiple abscess cavities containing sequestrae, often associated with cloacae and multiple sinus tracts. There is usually good structural integrity of the bone. A healthy vascular response by the involucrum may eventually resorb remnants of sequestrum, leaving multiple tiny abscesses and sequestrae (Fig. 31.6). The appropriate surgical procedure is a widespread saucerization (sometimes called a "canoe" saucerization or longitudinal partial diaphysectomy), opening a lengthy section of medullary canal to access all the walled-off abscesses and microsequestrae. With many small abscesses, it is important to plan a surgical approach that does not remove excessive bone and compromise its structural integrity. Look for and begin

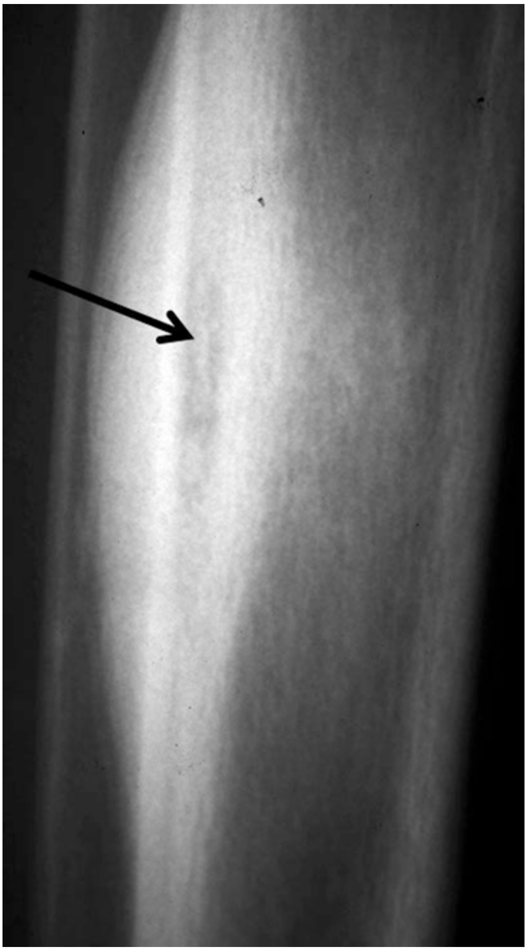

Fig. 31.4 In the cortical presentation, the sequestrum becomes walled off within the cortex of the bone. In this case the arrow points to a thin sclerotic sequestrum within the thickened cortex

with the locations with the most obvious sequestrae and those causing the most functional disability.

Presumably, if left alone, these cases might progress to one of the sclerotic types or heal spontaneously as the last remnants of sequestrae are absorbed, making a watch and wait approach, along with long-term antibiotic therapy to reduce the bacterial load, a reasonable approach, while allowing the involucrum to mature. These patients require hospitalization preoperatively for antibiotics and nutritional support.

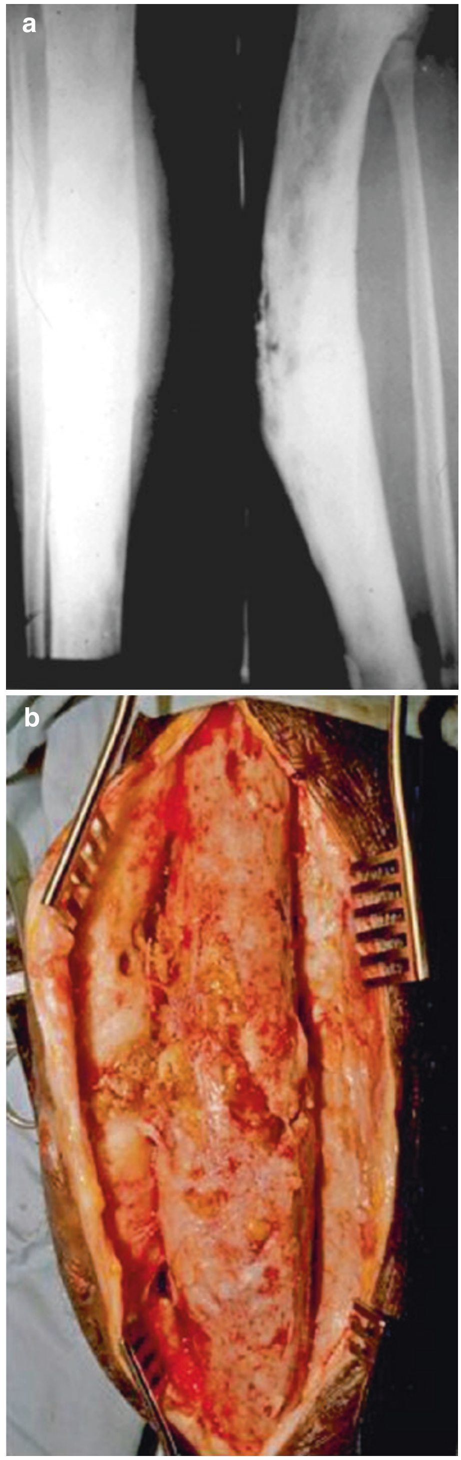

Fig. 31.5 This case illustrates the walled-off abscess presentation with (**a**, **b**) extensive involvement of the tibial shaft. (**c**) A longitudinal partial diaphysectomy/saucerization is required to facilitate debridement in such cases

Fig. 31.5 (continued)

Fig. 31.6 Walled-off multiple abscess presentation with many very small abscesses throughout a long section of diaphysis

In *metaphyseal presentation* (Fig. 31.7), the infection is loculated in the metaphysis. Micro-sequestrae can form from trabecular necrosis, and the abscess cavity can be quite large due to the relative sponginess of the metaphyseal bone. The single or multiple walled-off abscesses may show a sclerotic margin or juxtacortical erosions. The surgical approach is limited saucerization and curettage, and the lesions usually reconstitute without requiring bone graft.

The Beit CURE Classification

The Beit CURE radiologic classification system was developed by orthopedic surgeons in Malawi, expanding the Penny classification by including the long-term complications of joint dislocations, AVN, and growth arrest in their scheme [2] (Table 31.2).

Adequate Debridement

The timing of debridement is of paramount importance (Fig. 31.8).

In the earlier phase of chronic osteomyelitis, a large diaphyseal sequestrum may be seen with early or immature involucrum that does not bridge the defect. On x-ray immature involucrum appears fluffy and patchy. The retained sequestrum provides a template for involucrum growth, and removing the sequestrum often results in curtailment of further involucrum formation, a bone defect, and an unstable limb. While it is important to ensure adequate drainage of pus, it is worthwhile to delay sequestrectomy to allow

Fig. 31.7 Metaphyseal presentation

Table 31.2 Beit CURE radiologic classification of chronic osteomyelitis

A. Brodie's type	No sclerosis, one or more abscesses
B. Sequestrum and involucrum (B1–4)	B1. Localized cortical sequestrum
	B2. Sequestrum with normal involucrum
	B3. Sequestrum with sclerotic involucrum
	B4. Sequestrum without structural involucrum
C. Sclerotic	Extensive sclerosis and abscesses
Unclassifiable	

Physeal damage: add "P" if proximal physis or "D" if distal physis is damaged

further involucrum growth and maturity, potentially bridging the gap. This may entail waiting 3–6 months for definitive surgical care.

The importance of maintaining stability by external fixation at this stage cannot be overemphasized. Involucrum growth is enhanced by stabilization, and cast stabilization is less effective and more troublesome due to the purulent drainage. Once the involucrum bridges the gap and is robust enough to provide diaphyseal stability, the sequestrum can be removed.

In later stages of atrophic chronic osteomyelitis, where mature involucrum has not bridged the gap or is absent due to periosteal death, sequestrectomy leaves a segmental bone defect which requires reconstruction. In these cases external fixation is of great value to allow the infective process to heal in preparation for a reconstructive procedure.

For sequestrectomy or saucerization, base the incision on the location of draining sinuses, which suggest the location of cloacae, and over muscle away from subcutaneous borders. Plan the surgical approach to access the bone where the involucrum is least developed, leaving as much structural involucrum as possible, to avoid compromising its structural stability. Minimize subperiosteal stripping, which may further reduce the local blood supply. Use a drill to map an oval window in the cortex. Be aware that there is often no medullary canal. Remove the sequestrum in one piece, excavating the involucrum as necessary and curetting the intramedullary canal proximal and distal to remove any retained fragments. Feel and listen to the texture of the bone: sequestrae sound sharp and metallic on contact with a curette—involucrum sounds woody and muffled.

Where there are multiple abscess cavities or sequestrae, make sure to map them out radiographically prior to surgery, and perform a long enough saucerization to debride all the cavities.

Control of Bleeding

Chronic osteomyelitis is associated with considerable hyperemia; both the hyper-vascular involucrum and the surrounding soft tissues can bleed substantially during surgery. The hemoglobin should be checked preoperatively and blood cross-matched in anticipation of the need for transfusion. Blood supplies are often scarce or unobtainable, and blood-borne pathogens remain a concern.

Fig. 31.8 Resorption of sequestrae. This case of proximal humeral osteomyelitis was initially treated by drainage of the abscess and antibiotics. (**a**) The upper segment of the humeral shaft became sequestered. Early immature involucrum is seen developing. (**b**) The involucrum matured over time and (**c**) only a small sequestered fragment in the upper metaphysis persisted and needed removal

The femur and humerus are the most troublesome locations for significant bleeding. Suggestions to control blood loss include working quickly and efficiently, using a tourniquet (even in the face of sickle cell disease), placing the patient in Trendelenburg during lower extremity surgery, packing cavities with sponges when they are not being worked on, having your assistant elevate the limb straight up, and elevating the extremity postoperatively. Elevation of the foot or head of bed on bed blocks is more effective than using pillows.

Dead Space Management

Begin the closure by beveling the edges of the cortical window, and if available, mobilize healthy muscle to lay in the defect (Fig. 31.9). Suture the muscle to holes drilled in the involucrum with absorbable sutures. Avoid closing the subcutaneous tissues, but loosely re-approximate the skin edges with nonabsorbable sutures, preferably monofilament (Fig. 31.10a–d). Leave a drain—even gauze packing—in the wound.

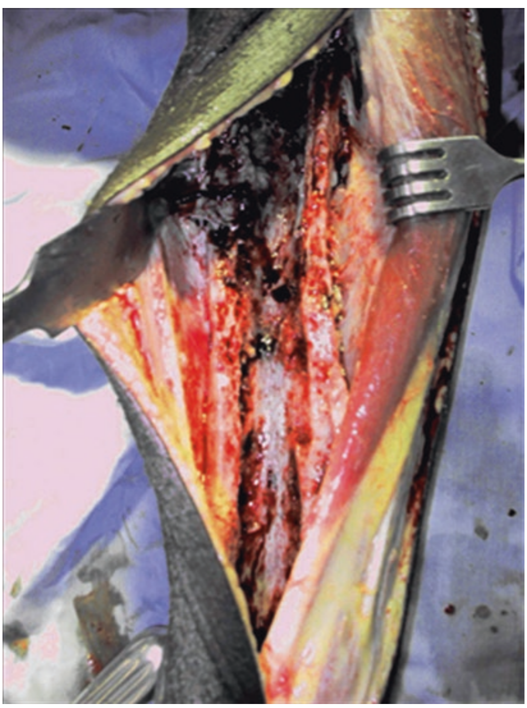

Fig. 31.9 The incision was placed laterally over the anterior compartment muscles which will be mobilized and laid into the defect created by the sequestrectomy. This fills the dead space and enhances vascularity

Rehabilitation and Reconstruction

Postoperative recovery can be prolonged, requiring dedicated nursing care and physiotherapy. Achieving stability, especially in the atrophic presentation with deficient involucrum, is of maximum importance. Protected weight-bearing and external fixators may be necessary if the involucrum is not well established. For many patients it is impossible to accomplish this care on an outpatient basis, and long-term hospitalization is necessary. Wherever rehabilitation wards and facilities are available, they should be used. A much neglected but vitally needed facility in many under-resourced countries is the step-down rehabilitation hostel in the local community. Surgeons should encourage community-based rehabilitation programs to institute hostel care.

Long-Term Complications of Chronic Osteomyelitis and Their Treatments

Complications associated with chronic osteomyelitis include, but are not limited to, focal or segmental bone defects, angular deformities, leg length discrepancy, physeal disturbance, pathologic fracture, and squamous cell carcinoma from chronic sinus tracts (Fig. 31.11).

Focal bone loss can be treated by bone grafting if the defect is not greater than 1–2 cm and ideally there is some bony continuity, and the open cancellous bone grafting technique (Papineau) can be considered when the subcutaneous surface of the bone is involved especially in the setting of soft tissue loss (see Chap. 41 and Appendix 3—Bone Grafting).

Segmental bone defects are a common complication, and salvage bypass procedures are an option for those in the forearm (Fig. 31.12) or lower leg (Fig. 31.13). Options in the lower leg

Fig. 31.10 For chronic calcaneal osteomyelitis, the heel splitting approach can be used for debridement. (**a**, **b**) This adolescent had an open wound for more than 1 year and (**c**, **d**) underwent excision of the sinus tract and wide resection of the infected focus, followed by loose re-approximation of the wound edges

include posterolateral grafting, and a pro-fibular bypass can be accomplished by traditional Huntington fibular transfer, or “spot welding” the proximal and distal tibia by focal bone fixation and grafting, creating a one-bone lower extremity. Similar procedures to create a single bone forearm can restore stability and preserve useful elbow function but with loss of pronation and supination. The Masquelet technique has also been used in the pediatric population and can prepare the periosteal bed for grafting (see Chap. 41).

Segmental defects in the femur or humerus are more difficult to manage (Fig. 31.14). External fixation can maintain length, while the tissues heal, followed by grafting, transport, or vascularized transfer. These techniques require more sophisticated training and surgical resources but are increasingly available in low-resource circumstances (Fig. 31.15).

Once the infection is eradicated, and structural integrity of the bone established, there are often residual limb deformity issues of angular malalignment, mechanical axis deviation, limb

Fig. 31.11 Complications of osteomyelitis include (**a**, **b**) segmental bone loss, (**c**) angular deformities from physeal damage and growth disturbance, (**d**) limb overgrowth (leg length discrepancy) from chronic hyperemia, (**e**) limb shortening, and (**f**) pathologic fracture

length inequality and joint incongruency. Angular deformities are managed by osteotomy with an acute correction for deformities ≤20° or gradual correction using Ilizarov or Taylor Spatial frame external fixators for more severe deformities. Reconstruction for limb length discrepancy may be treated by an epiphysiodesis of the contralateral side if sufficient growth remains or by lengthening procedures (see Chaps. 35 and 36).

Fig. 31.12 (**a**, **b**) Segmental bone loss and wrist instability treated by creation of a single bone forearm and wrist fusion as there was insufficient distal radial bone stock to synostose the distal ulna to the distal radius

Fig. 31.13 Numerous techniques have been described for using the fibula to bypass segmental defects in the tibia from nonunion or infection. (**a**–**d**) In this case, following debridement, a bypass procedure was performed in which a side-to-side union of the tibia and fibula was achieved following bone grafting and fixation. Fibular bypass procedures can be performed in one or two stages, with or without translation of the fibular shaft under the mechanical axis of the tibia (centralization). (**e**, **f**) show other examples of synostosis without centralization. (**g**) The fibula is capable of significant hypertrophy when centralized under the tibia. This radiograph was obtained at 8-year follow-up, and while there was no reactivation of infection, the case was complicated by ankle valgus and the patient elected to have a procedure for realignment

Fig. 31.14 Segmental loss in the humerus is more difficult to manage. This young girl had an early debridement and ended up with loss of the lower humerus and the proximal radius and ulna. Her neurovascular exam was normal distally, but she was unable to use the extremity in any activities of daily living

Fig. 31.15 (**a**–**f**) Acute bone transport at the time of sequestrectomy. (**a**–**b**) X-rays of atrophic osteomyelitis with proximal tibial sequestrum. (**c**) X-ray after sequestrectomy and simultaneous distal tibial corticotomy. (**d**) Docking with well-formed regenerate bone without grafting. (**e**–**f**) Final result at 2-year follow-up

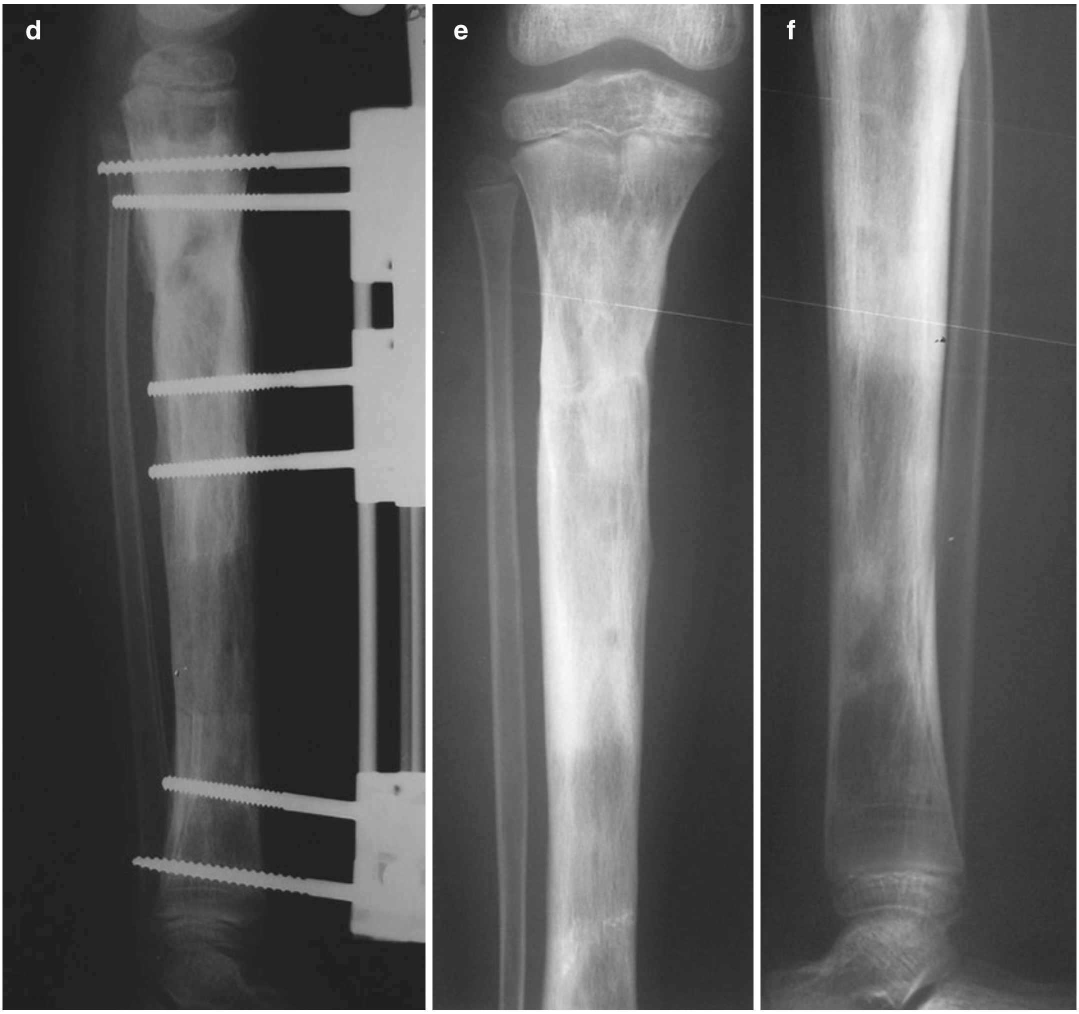

Fig. 31.15 (continued)

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32 Osteomyelitis and Septic Arthritis in Adults

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Osteomyelitis

Adults with osteomyelitis commonly present with subacute or chronic disease from (1) reactivation of childhood chronic osteomyelitis, (2) open fractures, or (3) as a complication of musculoskeletal surgery. The offending organisms attach to avascular structures and become covered in an extracellular biofilm matrix which shields them from host defenses and antibiotics. Chronic osteomyelitis originating in childhood may remain active into adult life or may go through periods of dormancy with later reactivation. Reactivation can be spontaneous or provoked by an insult such as impaired immunity, trauma, or surgery.

While bacteremia and malnutrition are more common in children, infection-enhancing comorbidities such as HIV, diabetes mellitus, vascular disease, malignancy, and alcohol/tobacco abuse are more common in adults. In low-income countries, open fractures commonly become infected due to delayed or inadequate care. ORIF of closed fractures is often complicated by sepsis because of suboptimal facilities, poor sterile technique and tissue handling, unstable fixation, and unhygienic perioperative care. The most common infecting organism is *Staphylococcus aureus*. The history may provide clues to less common pathogens such as salmonella in sickle cell and HIV patients and mixed pathogens from animal and human bites.

Diagnosis

The periosteal reaction to infection, involucrum, is less robust in adults when compared to that in children, and the structural integrity of the bone must be assessed to determine the risk of pathologic fracture. Routine blood tests such as a CBC, ESR, and CRP should be obtained if possible but are often normal in chronic osteomyelitis in the absence of an acute exacerbation. Additional helpful tests include blood cultures and serum chemistries including glucose, HIV, and serum protein (albumin). Deep cultures of pus, bone, and tissue around implants should always be taken, as external cultures from the skin or sinus tracks often grow mixed species and are less helpful. CT scanning can be helpful for identifying sequestra and MRI for abscesses and active infection.

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Treatment

In the early stage of acute osteomyelitis, <2 weeks duration, there is typically no bone death or sequestration, and it may be adequately managed by antibiotics and surgical drainage of abscesses.

Adult chronic osteomyelitis is a surgical disease, and antibiotics should be viewed as an adjunct. The surgical principles used to treat a locally aggressive neoplasm are the most appropriate when dealing with chronic osteomyelitis, with the goal of a wide resection of the infected tissues followed by reconstruction of soft tissues and bony defects. Treatment of other problems such as angular deformity and limb length discrepancy may be required in the reconstructive phase (see Chap. 31).

The importance of medical management in all stages of adult bone infection to enhance host defenses and maximize healing potential cannot be overemphasized. Patients seropositive for HIV should be staged according to the guidelines of the World Health Organization [1], and antiretroviral therapy should be started although it will takes several weeks to be effective. Check for undiagnosed diabetes mellitus and maintain acceptable sugar levels. Nutritional optimization is essential for the host to overcome musculoskeletal infection. Cessation of smoking and ethanol are essential.

Adult osteomyelitis is most commonly staged according to Cierny and Mader [2] (Table 32.1). This system considers both (1) anatomic type of infection (medullary, superficial, localized, diffuse) and (2) host status (medical comorbidities). The "A" host is healthy and has the best chance of an excellent outcome with aggressive surgical therapy aimed at disease eradication and limb reconstruction. The "B" host has local (chronic edema, vascular disease) and/or systemic (diabetes, malnutrition, immune deficiency) comorbidities that increase the risk of treatment failure. Limb salvage is not an option in "C" hosts in whom the risks of treatment, except palliative therapy, are greater than living with a chronic bone infection. The anatomic type of the infection determines the appropriate surgical approach based on the anatomic pathology, whereas the host status governs whether an aggressive, palliative, or ablative approach is selected.

Decision-making is facilitated by knowledge of the patient's clinical condition, expertise of the clinician, local facilities, economics, and sociocultural factors. A visiting surgeon should be cautious and sensitive to all these issues and ask for input from local caregivers. The visitor must also be sure that the treatment can be completed in his or her absence. There may be times when dependent drainage is the best treatment. The primary goal is to improve the patient's quality of life, and on occasion the risks of limb salvage may outweigh the benefits. If ablative surgery is considered, the surgeon must take stock of local availability and affordability of prosthetics prior to embarking on a shared decision-making approach with the patient and local staff.

While debridement of all infected tissues is necessary, dead space management and reconstructive needs vary. Some of the tools are resource intensive and impractical; however, the general principles are crucial and can be adapted for use when resources are limited. The place of incision for dependent drainage is the most important factor. While sinograms can be considered, we prefer to pass a probe or curette intraoperatively to define the sinus track. The biological environment must be respected by careful tissue handling and avoiding subperiosteal stripping and placement of circumferential retractors.

Both sequestra and involucra are harder to define in adults than in children. It is generally easier to perform the debridement with a tourniquet inflated and through an oval cortical window (Fig. 32.1). The tourniquet can be deflated to assess the adequacy of debridement. Exposed viable cortex bleeds in a uniform Haversian pattern, and cancellous bone bleeds in a sinusoidal pattern, termed the "paprika sign."

Dead space management may include polymethyl methacrylate spacers that provide local antibiotic delivery in high concentration and temporary structural support prior to definitive bony reconstruction. The role of intravenous or oral antibiotics is not well defined, and we recommend that they be considered as an adjunct to aggressive surgical care. A 24-h perioperative

Table 32.1 Cierny-Mader classification of adult osteomyelitis

Anatomic type	Description	Initial surgical debridement and dead space management	Reconstruction
I: Medullary	Biofilm nidus in endosteum (scar, implant, dead bone)	Unroofing by corticotomy, canal reaming, or both	Dead space in medullary canal managed by bone grafting
		± antibiotic depot (PMMA)	
		± primary closure	
		Protect if fracture risk (cast or ex fix)	
II: Superficial	Nidus is an exposed bony surface, no medullary involvement	Soft tissue loss is main concern	Local transposition flap
		Superficial bony debridement	
III: Localized	Full thickness, cortical sequestrum, medullary involvement, soft tissue defect possible	Combination of types I and II	Local transposition flap dead space in medullary canal managed by bone grafting
		Bony and soft tissue defects	
		Protect if fracture risk (cast or ex fix)	
		± Antibiotic depot (PMMA)	
IV: Diffuse	Permeative bony destruction which is often circumferential, unstable	Most difficult, treatment is always staged	Strategies used alone or
			in combination include
		Extensive debridement causes bony instability or segmental defect	(1) Acute shortening
			(2) Bone transport
		± Antibiotic depot(PMMA)	(3) Bypass procedures
		Protect if fracture risk (cast or ex fix)	(4) Osteotomy with or without lengthening

Source: Cierny [2]

course will suffice for most patients, especially when access to antibiotics is limited. The need for long-term antibiotic therapy must be assessed on a case-by-case basis. Management of retained implants must be considered and depends on the degree of healing when the infection is diagnosed. In early infections, it may be best to perform an initial irrigation and debridement while retaining the implants if they are secure, followed by their removal once union has occurred. It is easier to treat an infected union than an infected nonunion.

Once the local environment has been sterilized by debridement and the sepsis controlled, options for reconstruction of localized or segmental defects include (1) acute shortening, (2) cancellous bone graft, (3) structural free autograft, (4) structural allograft, (5) vascularized autograft, (6) bone transport, and (7) bypass procedures (forearm or lower leg).

Acute shortening up to 2 cm in the lower limb is generally well tolerated and can be offset by a shoe lift. A bigger challenge is how to stabilize and compress the site. External fixators may provide sufficient stability to promote union but are often difficult for patients to manage. Internal fixation may provide greater stability for bone healing; however, there is an increased risk of local wound sepsis. Internal fixation can successfully treat septic nonunions if the biological and mechanical environments are optimized, for example, with an intramedullary implant. Internal fixation from both inside (intramedullary device) and outside (plate) will cause cortical necrosis, and this "dead bone sandwich" has a very high risk of becoming infected. Cerclage wiring almost guarantees necrosis of the segment and should be avoided at all costs.

Cancellous grafting is useful for localized bone defects. Structural free grafts, such as the fibula, which are useful in children are a concern in adults since avascular bone is inserted into tissues which were previously infected. In addition, donor site morbidity should also be considered. Vascularized autografts are usually beyond the capabilities of austere environments.

Bone transport using a monolateral or ring fixator is an option for defects greater than 2 cm in

Fig. 32.1 (**a**) This case of tibial osteomyelitis with two thin sequestrae visible along the anterior open area of the cortex of the proximal tibia was (**b**) treated by sequestrectomy and debridement. Further management might include open cancellous bone grafting or gastrocnemius flap. (Courtesy of Dr. Sam Baker)

facilities with adequate equipment, expertise, and rehabilitation services and in patients who can sacrifice the time and money involved (Fig. 32.2).

Soft tissue coverage can often be achieved with local fasciocutaneous or other flaps when primary or delayed primary closure is not an

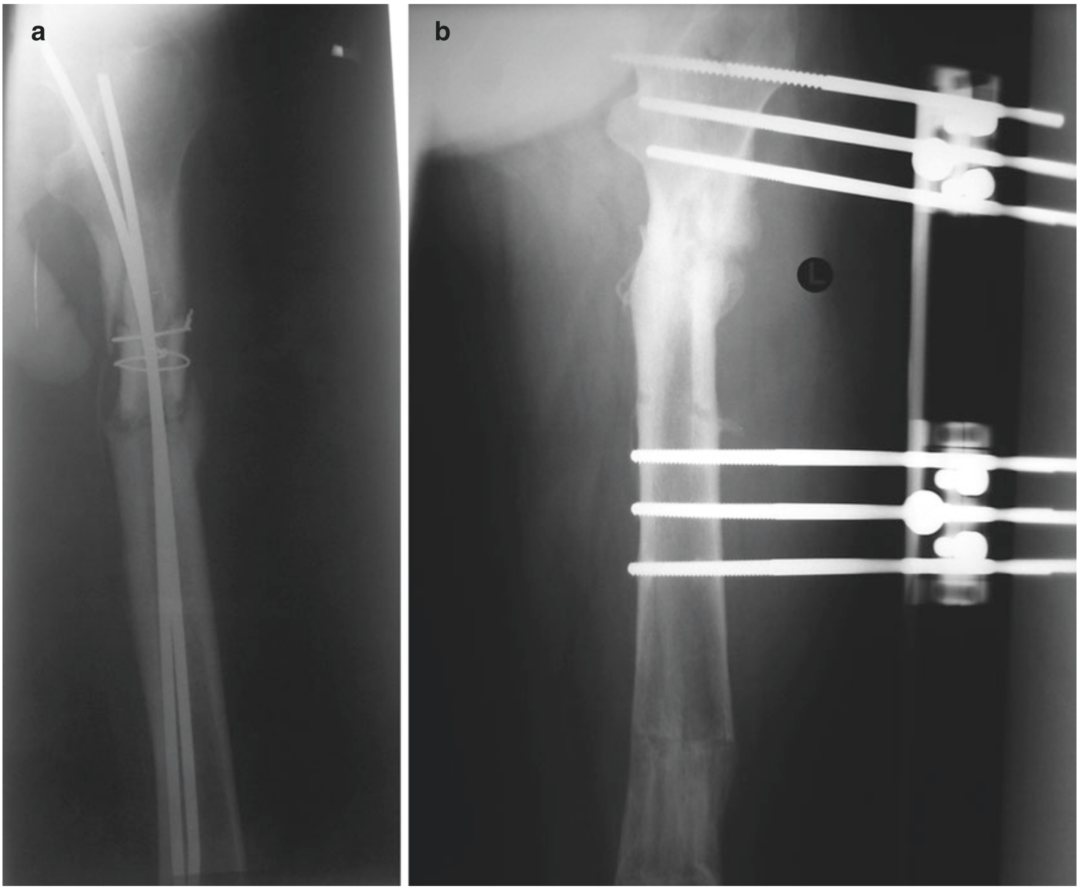

Fig. 32.2 (**a**) A 17-year-old male presented 6 months after sustaining an isolated closed fracture of his left femoral shaft in a road traffic crash that was treated surgically with two retrograde flexible nails and a cerclage wire. Cerclage wiring almost guarantees necrosis of the segment and should be avoided. He developed wound sepsis. The flexible nails had backed out and been hammered back up, transgressing the hip joint. At presentation he had purulent drainage, scarred soft tissues, and stiffness of both the hip and knee. (**b**) He was treated by debridement of 6 cm of devitalized bone and removal of implants. The bone defect was filled with gentamicin beads, and a monolateral external fixator was applied. The beads were removed after 2 weeks, and a third set of pins were inserted distally to facilitate corticotomy and bone transport

option (see Chap. 14). Vacuum-assisted wound closure or negative-pressure wound therapy is useful and can be made simply and economically (see Appendix 4).

It is vital to think of rehabilitation and restoration of function from the outset of treatment, as muscle atrophy is common and ongoing sepsis exacerbates joint stiffness. An aggressive approach to infection control and stability management is required for rehabilitation (Fig. 32.3).

To justify the morbidity and risk of limb salvage, the expected outcome must offer distinct advantages over an amputation or observation alone. If treatment for cure in the given setting is contraindicated or excessive, the patient is classified as a C-host and offered palliation such as I&D, suppressive antibiotics, or ambulatory aides.

Amputation is typically reserved as a salvage option but should also be considered in selected patients as the primary treatment to enhance outcomes and facilitate rehabilitation (Fig. 32.4). Amputations should include an adequate debridement with wounds left open initially (see Chap. 43).

A recent PRISMA-guided systematic review of treatment of chronic osteomyelitis in all ages

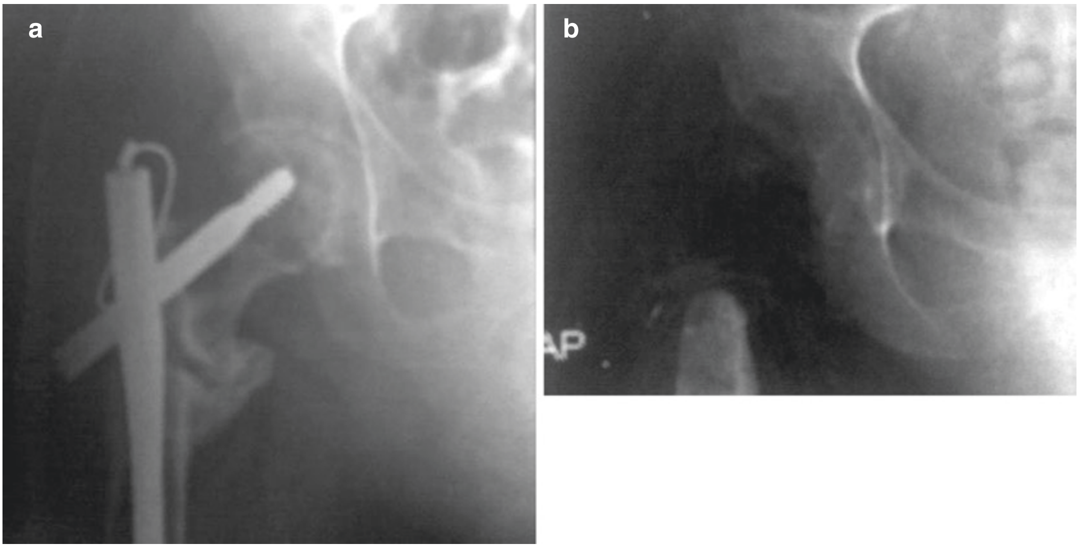

Fig. 32.3 (**a**) This 46-year-old multi-substance abuser sustained a closed subtrochanteric femur fracture. Treatment was complicated by nonunion. After several additional surgeries, he developed a chronic MRSA osteomyelitis (**b**) which ultimately required an extensive Girdlestone arthroplasty with resection of the proximal femur

in low- and middle-income countries has been published but concluded that no definite guidance could be given regarding evidence for optimal treatment [3].

Adult Septic Arthritis

Septic arthritis can be due to bacteria, viruses, fungi, and parasites. The defense mechanisms of the host, properties of the invading organism, and the premorbid condition of the joint play important parts in the pathophysiology of septic arthritis. Joint sepsis can result from hematogenous dissemination, direct inoculation, or contiguous spread from an adjacent osteomyelitis. Synovial fluid is an excellent growth medium for bacteria and has a relative lack of immunologic resistance, and there is no structural barrier to the spread of bacteria from the synovium to the joint. Transient bacteremia and trauma causing intra-articular hemorrhage can play a role in the pathogenesis of septic arthritis.

Risk factors for septic arthritis include systemic disorders (rheumatoid arthritis, diabetes, drug abuse, malignancies, HIV/AIDS, or immunocompromised status), local factors (trauma, osteoarthritis, injections, and surgery), age (elderly), and social factors (low income, exposure to animals). The differential diagnosis includes crystal-induced arthritis (gout, pseudogout), rheumatoid arthritis, chronic seronegative arthritis, Lyme disease, drug-induced arthritis, and seeding from infectious endocarditis.

Ninety percent of infections are monoarticular with primary knee sepsis accounting for 40–50%, hip 20–25%, and shoulder 10–15%. Polymicrobial infections occur in 5–15% of patients, often associated with an extra-articular polymicrobial infection or penetrating trauma, especially in immunocompromised patients. Staphylococcal species are most common, followed by streptococci. Gram-negative infections are more common in the elderly, intravenous drug users, and those with malignancy, diabetes, immunosuppression, or hemoglobinopathy. Host variables help predict the bacteria involved (Table 32.2).

Patients with joint infections secondary to *N. gonorrhoeae* are generally young, healthy adults. The most common clinical manifestation is a migratory polyarthralgia, with fever, tenosynovitis, and dermatitis commonly seen on initial examination.

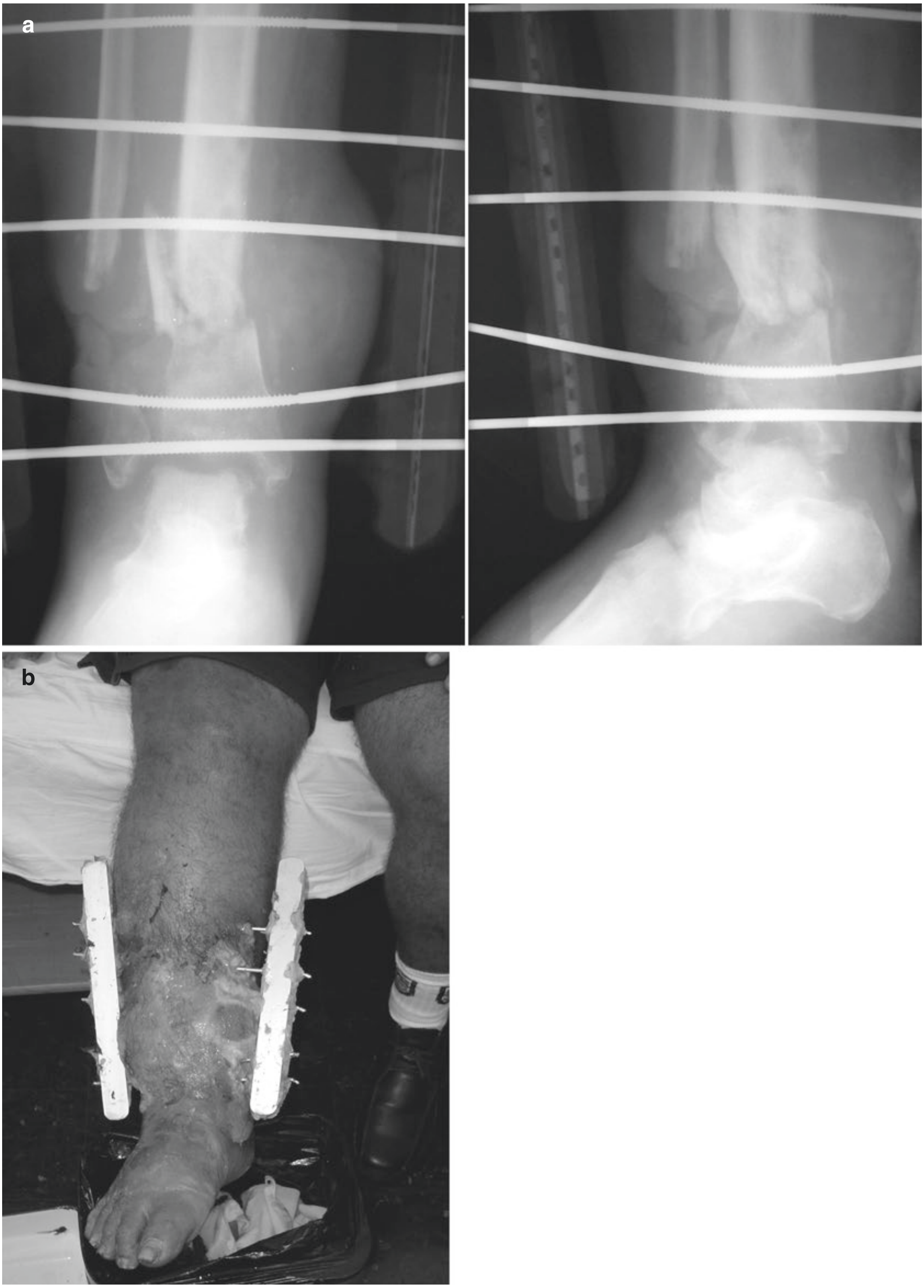

Fig. 32.4 (**a**) This comminuted open fracture was treated with a locally made fixator. (**b**) It became infected, leading to a below-knee amputation

Table 32.2 Septic arthritis in selected clinical settings

Clinical setting	Risk factors	Pathogen
Rheumatoid arthritis	Disabling arthritis	*Staphylococcus aureus* (40–60%)
	Skin lesions	*Streptococcus pyogenes* (10–20%)
	Infected rheumatoid nodule	
Advanced age	Diabetes mellitus, urinary tract infection, biliary tract infection, diverticulitis	*Staphylococcus aureus* (30–40%) Gram negatives (10–20%)
Immunosuppression, AIDS	Decreased humoral- and cell-mediated immunity	Atypical organisms (salmonella, *Agrobacterium*, fungi, atypical mycobacteria)
Hemoglobinopathy	Microinfracts in intestinal wall	Salmonella, *Staphylococcus aureus*
Human and animal bites	Inoculation of indigenous mouth flora	*Pasteurella multocida*, *Eikenella corrodens*, *Streptobacillus moniliformis*
Intravenous drug use	Endocarditis, discitis	*Staphylococcus aureus* (60–80%), *Pseudomonas aeruginosa*, *Candida* species
Plant thorns	Puncture wound, foreign body	Atypical organisms (*Pantoea agglomerans*, sporotrichosis, mycobacteria, nocardia, *Clostridium sordellii*, actinomycosis)
Aquatic environment		*M. marinum*

Joint aspiration yields a positive Gram stain in only 25% of the cases and 50% of cultures test negative. Synovial fluid white cell counts are less than those for nongonococcal septic arthritis but are usually greater than 50,000 (WBC)/mm. Urethral, cervical, rectal, and pharyngeal cultures have a much higher yield and should be taken from any sexually active patient suspected of having gonococcal arthritis. The infection shows a rapid response to ceftriaxone, and the arthritis generally resolves in 48–72 h. Surgical decompression is not needed in most cases, because joint destruction is rare.

Patient Evaluation

Clinical signs and symptoms of septic arthritis are variable and imprecise. The key to diagnosis is a thorough clinical history and physical examination, which often shows intense joint pain and limited passive range of motion, along with laboratory studies of the synovial joint fluid. Occasionally patients are systemically septic.

The WBC count may be normal to slightly elevated and may not show a peripheral blood leukocytosis, while the ESR is consistently elevated. The CRP increases more rapidly than the ESR. Blood cultures should be obtained from all patients with clinical signs and symptoms of systemic sepsis.

Joint aspiration followed by synovial fluid analysis and culture is essential. On gross examination, the fluid is often thick, yellow, and cloudy. There may be a negative “string sign.” Values greater than 50,000 WBC/mm^3 on the cell count are suggestive of bacterial arthritis, and values greater than 100,000 WBC/mm^3 are rarely associated with other causes. The percentage of polymorphonuclear lymphocytes is typically more than 75% in bacterial infections versus >50% in inflammatory diseases and <25% in noninflammatory conditions. Cultures should include aerobes, anaerobes, fungi, and mycobacteria. In cases where *N. gonorrhoeae* is suspected, chocolate agar or Thayer-Martin plates should be used. Polarized microscopy may be helpful, recognizing that the presence of crystals does not rule out infection, because the two processes can coexist.

Plain radiographs are only occasionally helpful within the first 7–10 days and may show joint subluxation or soft tissue swelling, due to either joint effusion or synovial hypertrophy. Later in the infectious process, 40% of patients will show abnormalities. Ultrasound can be helpful, especially for the hip joint.

We classify adult septic arthritis based on the (1) site and extent of tissue involvement (four anatomic types), (2) host’s status (the same A, B, and C classes used in the Cierny-Mader classification for osteomyelitis in adults (Table 32.1)),

Table 32.3 Classification system for septic arthritis

Joint name (glenohumeral, elbow, hip, knee, etc.)
Anatomic type
I: Periarticular soft tissue infection without pyarthrosis
II: Isolated septic arthritis
III: Septic arthritis with soft tissue extension, but no osteomyelitis
IV: Septic arthritis with contiguous osteomyelitis
Host class
A: Normal immune system
B: Compromised host
B_L: Local tissue compromise
B_S: Systemic immune compromise
C: Risk associated with aggressive treatment unwarranted
Clinical setting
1: Less than 5 days of symptoms and non-virulent organism
2: Symptoms for 5 days or more, or a virulent organism
Clinical stage for a specific joint
Anatomic type + host class + clinical setting = stage

(3) duration of symptoms, and (4) virulence of the organism (Table 32.3).

Anatomic Type I is periarticular soft tissue infection without pyarthrosis, for example, a postsurgical superficial wound infection. Anatomic Type II occurs when the purulent material is confined within the capsule. Anatomic Type III exists when there is involvement of the joint and surrounding soft tissue, such as deep wound infection or septic bursitis, along with the joint sepsis, but no bony involvement. When there is osteomyelitis contiguous with a joint infection, it is classified as Type IV.

The clinical setting takes into account the duration of symptoms and aggressiveness of the organism. We have grouped patients with less than 5 days of symptoms and infection with a less virulent bacterial strain into group 1. Those patients who are infected with a virulent organism or with symptoms for 5 days or greater fall into group 2. The cutoff was chosen at 5 days because animal studies have shown that irreversible joint damage occurs if septic arthritis persists beyond this time. The virulent organisms may vary between hospitals and geographic locations but generally include methicillin-resistant *S. aureus* (MRSA) and Gram-negative organisms.

Treatment

Empiric antibiotics—based on availability, history, and local prevalence of organisms—are instituted after a specimen is taken for the appropriate studies. Usually, a penicillinase-resistant anti-staphylococcal drug is the initial choice for the typical Gram-positive cocci infection. A more controversial issue is the use of oral versus parenteral antibiotics. Patients are typically started on intravenous therapy and converted to oral therapy if they exhibit an adequate clinical response, manifested by improved ROM of the joint, decreased pain, resolution of fever, as well as normalization of WBC and ESR.

The duration of antibiotic therapy varies with the pathogen, the patient's underlying condition, and adjuvant medical or surgical procedures. It is typically 2–6 weeks as long as an appropriate clinical response is observed. A 4- to 6-week course of antibiotics is required with more virulent organisms such as *S. aureus* or Gram-negative bacilli, immunocompromised patients, or those who show a slow clinical response.

The goals of treatment of septic arthritis include sterilization and decompression of the joint. In non-surgery-related infections, the preferred method of joint decompression remains controversial, and options include repeated needle aspirations (one to two times per day until effusion is gone) under sterile conditions with a large bore needle versus surgical drainage (open or arthroscopic). Recognizing the increased costs, morbidity, and recovery time following arthrotomy (versus aspiration), the authors' opinion is that open surgical drainage should be performed when:

- Patients present with >5 days of symptoms.
- Infection is caused by aggressive organisms (MRSA, Gram negatives).
- Host variables are poor (postsurgical, immunocompromised, coexisting diseases, elderly).
- Postsurgical cases.
- Cases in which a biopsy or synovectomy would be useful.
- Repeated arthrocentesis failed.

Cultures of synovial tissue may have a higher yield for fastidious organisms.

Although sterilization of a joint may be achieved with irrigation and antibiotics, residual bacterial products may contribute to a post-infectious synovitis. We usually start NSAIDs after initiation of antibiotic treatment to blunt this synovitis. Finally, as articular cartilage is nourished by synovial fluid, active and passive range of motion should begin as soon as the acute symptoms subside.

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Tuberculosis

33

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and Binod Bijukachhe

General Principles

Tuberculosis continues to be a major public health problem globally and is commonly encountered in areas with crowding, malnutrition, poor sanitation, and where access to preventive and curative health services is scarce or absent.

Mycobacterium tuberculosis is transmitted through inhalation of airborne droplets disseminated by individuals with pulmonary tuberculosis. The microorganisms are ingested by alveolar macrophages, and the infection is either contained or develops into active disease. Active disease is most common in children younger than 5 years and adults with HIV/AIDS. The incidence of extrapulmonary tuberculosis is increasing due to the increase in the prevalence of HIV/AIDS.

Musculoskeletal involvement is diagnosed in less than 10% of all cases of tuberculosis, and 50% of these patients have spinal involvement. Tissue destruction in tuberculosis is caused by a delayed hypersensitivity reaction, leading to inflammation, tissue exudation, and liquefaction, producing a cold abscess. These can migrate along tissue planes and exit the skin at sites remote from their origin, such as those from the spine draining through the inguinal or gluteal region (Fig. 33.1a, b). Though uncommon, multiple osseous and/or articular sites can occur in patients with significantly impaired host defenses. As the prognosis relates to the stage of disease at the time of presentation, early diagnosis and treatment improves patient outcomes.

Principles of Diagnosis

A diagnosis requires a high index of suspicion, especially in areas where the disease is not prevalent. Bone and joint tuberculosis is usually an indolent, slowly progressive disease, with patients often presenting with nonspecific consti-

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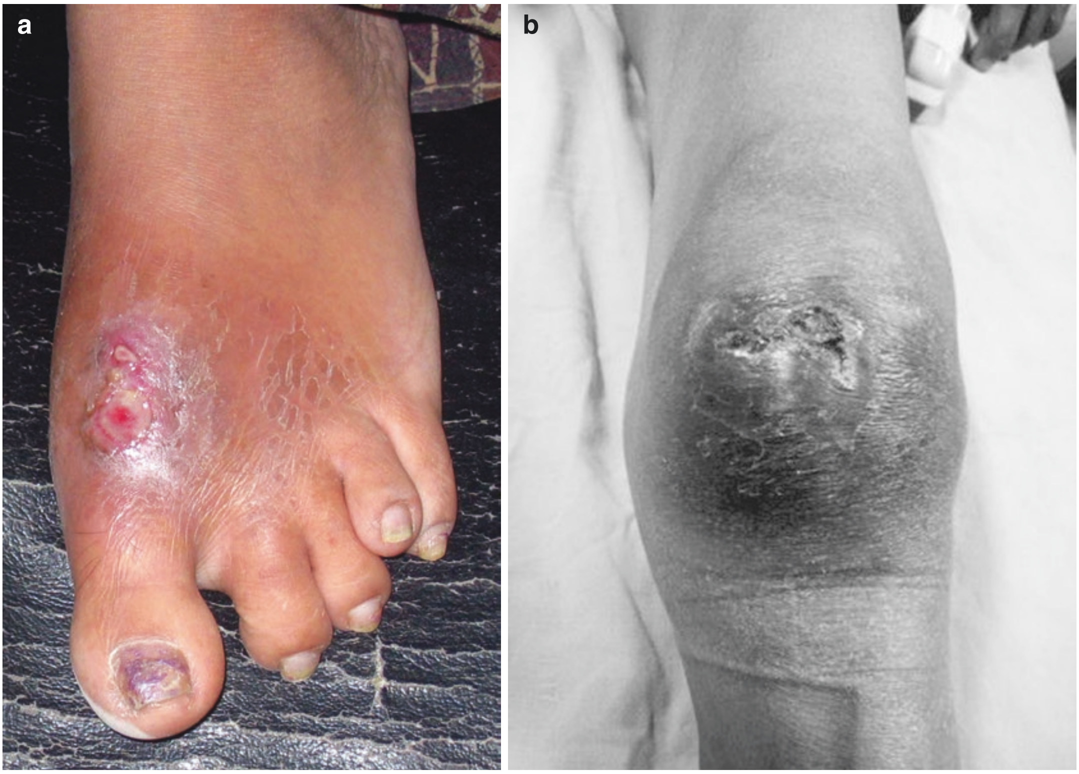

Fig. 33.1 (**a**, **b**) Sinuses often form as a complication of musculoskeletal tuberculosis. (Reprinted with permission from Spiegel et al. [16])

tutional symptoms such as low-grade fevers, night sweats, weight loss, anorexia, anemia, and malaise. Lymphadenopathy is common. Extremity involvement may present with localized pain and increased warmth, soft tissue swelling or effusion, loss of motion, and limp or gait disturbance. The initial evaluation includes a chest radiograph, complete blood count, and ESR. Normal acute phase reactants do not rule out the presence of tuberculosis. The purified protein derivative (PPD) tuberculin skin test is often positive in endemic areas or in patients who have received the BCG vaccination and does not correlate with active disease.

The microbiologic diagnosis of tuberculosis in austere settings depends on the evaluation of sputum smears, and smears and cultures of biopsy specimens, using Ziehl-Neelsen and Auramine O stains. Acid fast bacilli and granulomas seen on direct microscopy lead to the fastest diagnosis but are present in less than 50% of cases. A formal biopsy may be difficult to obtain especially in those with spinal involvement. Cultures are positive in up to 90% but often take 6–8 weeks to become positive.

Treatment Principles

Chemotherapy remains the mainstay of treatment for all forms of tuberculosis and is generally effective in 90% of cases. Surgery is indicated for (1) establishing the diagnosis and (2) treating complications of the disease. Ideally a biopsy and culture should guide therapy, but this is impractical in low-resource environments. Empiric chemotherapy is provided in many cases when the characteristic clinical and radiographic features are present. In previously untreated adults without known drug susceptibility, rifampin and isoniazid should be used throughout the duration of therapy, and another first-line drug, streptomycin or ethambutol, is chosen for the first 2 months along with one second-line drug.

Most patients with active TB are treated with 6–9 months of therapy [1, 2], though some practitioners favor treating spinal disease for 12–18 months. The WHO treatment guidelines should be followed [2], and systems for monitoring compliance, such as DOTS – directly observed therapy, short course – should be in place. A longer duration of chemotherapy may be indicated with documented cases of relapse and in patients who exhibit signs of persistent inflammation, known as slow responders. Specific recommendations are available for patients with recurrent disease and active disease associated with HIV/AIDS. In contrast to abscesses associated with bacterial sepsis, cold abscesses may resolve with chemotherapy, and drainage is not routinely required. Bacterial superinfection should be suspected when a sinus track fails to close following an adequate course of chemotherapy.

Lack of adherence to treatment with chemotherapy commonly leads to the development of resistant strains that are more difficult and costly to treat. DOTS regimens have been developed to counter this but require intense resources, which are often lacking. Screening for drug toxicity is limited, and patient education about side effects and potential complications of treatment is crucial.

Multidrug-resistant TB is defined as resistance to isoniazid and rifampicin, while extensively drug-resistant tuberculosis describes resistance to isoniazid, rifampicin, and several second-line drugs [3]. Most of these resistant cases reflect the failure of the system to provide the correct medications and dosages and to monitor treatment. The incidences of these worrisome entities are on the rise.

Osteomyelitis

Osteomyelitis is the least common form of musculoskeletal TB (5%), and the presentation is similar to subacute hematogenous osteomyelitis. Clinically, patients present with pain and soft tissue swelling, and both abscesses and sinuses are common. Most patients are adequately imaged with plain radiographs.

The differential diagnosis on plain radiographs is extensive and includes chronic osteomyelitis, Brodie's abscess, benign and malignant tumors, and other granulomatous diseases. While a lytic lesion with or without a sclerotic rim is the most common presentation, lesions may be serpiginous, commonly cross the physis, and may readily invade neighboring joints (Fig. 33.2a–d). An aggressive periosteal response can also be observed, and in such cases a biopsy is mandatory.

Sequestrae are unusual but can be present. The entire diaphysis can become sequestered in children due to intraosseous thrombosis. Disseminated skeletal tuberculosis can be observed in compromised hosts, involving combinations of osseous and articular involvement. Tuberculous dactylitis, spina ventosa, occurs in the short tubular bones of the hands and feet. X-rays show multiple layers of subperiosteal new bone, a finding diagnostic for tuberculosis (Fig. 33.2d).

Given this diversity in plain radiographs, a biopsy is helpful in establishing the diagnosis, recognizing that under selected circumstances empiric treatment is considered. While curettage is recommended at the time of biopsy, bone grafting is rarely required as the lesions heal with chemotherapy. In severe and recalcitrant lesions, antibiotic-loaded bone cement (polymethyl methacrylate PMMA) spacers may be considered as well. While rifampin has been shown to be unsuitable for delivery through bone cement, isoniazid and streptomycin have shown beneficial elution parameters [4].

Arthritis

The natural history of TB arthritis progresses over several years, beginning with synovial seeding or direct penetration from a metaphyseal focus and culminating with joint destruction. The host inflammatory response results in synovial hypertrophy and an effusion, although adult patients may present with minimal effusion, called dry or "sicca" arthritis. At this point, plain radiographs demonstrate periarticular osteopenia due to the hyperemic inflammatory response (Fig. 33.3). Granulation tissue develops at the

Fig. 33.2 While TB osteomyelitis is variable in radiographic appearance, (**a**) one common presentation is an ill-defined metaphyseal lucency which crosses the physis. (**b**) In this example there is an expansile lesion with a smooth periosteal reaction. (**c**) TB in the foot typically involves both osseous and articular structures. In this case there is involvement of the navicular, medial cuneiform, and lateral cuneiform, as well as the joints between these tarsal bones. (**d**) Tuberculous dactylitis or spina ventosa. (Reprinted with permission from Spiegel et al. [16])

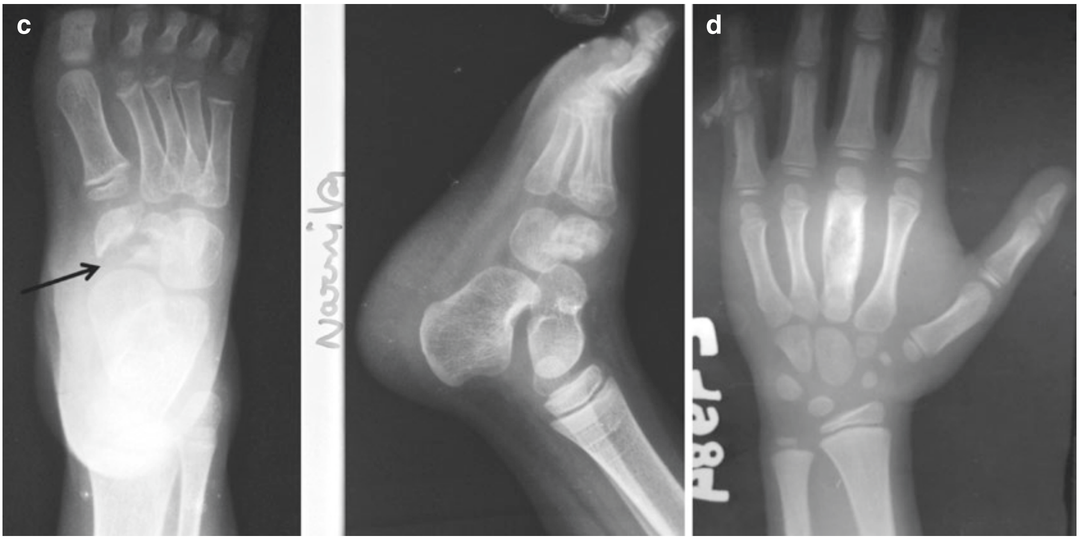

Fig. 33.2 (continued)

joint periphery leading to marginal erosions. As the disease progresses, this tissue extends across the joint surface directly damaging the articular cartilage (Fig. 33.4a, b). Other osseous abnormalities include osteophytes, chondrocalcinosis, and loose bodies. Ultimately, destruction of the joint occurs with or without subluxation or dislocation (Fig. 33.5a–c). Joints may also become ankylosed, often in a nonfunctional position.

The time course and evolution of pathologic changes are similar to that of an untreated chronic inflammatory arthropathy. Less common entities such as pigmented villonodular synovitis may also be confused with tuberculous arthritis, requiring a biopsy.

The clinical consequences are most profound in the larger, weight-bearing joints, especially the hip. Shanmugasundaram has classified the spectrum of morphologic abnormalities associated with mycobacterial hip disease into seven categories [5] (Fig. 33.6).

Other than biopsy, surgical intervention addresses complications of the disease, and procedures include synovectomy with or without joint debridement, osteotomy, arthrodesis, excisional arthroplasty, pelvic support osteotomy, and total joint arthroplasty.

During the early stages of TB arthritis, when changes are potentially reversible, treatment focuses on controlling discomfort with rest and restoring and maintaining ROM and strength. Adjunctive measures such as physical therapy, traction, serial casting, and/or splinting may help achieve or maintain motion, prevent deformity, provide comfort, and enhance strength. Weight-bearing is encouraged when comfort and an adequate ROM allow. The prognosis is excellent in the early stages, and the indications for synovectomy, with or without joint debridement, remain controversial.

Irreversible changes in the joint occur in the later stages, and salvage procedures can improve function. In cases where ankylosis is expected, the goal for some joints (wrist, knee, foot, and ankle) is to maintain a functional position by splinting or casting. When ankylosis would result in a decrease in function, for example, in the elbow, an excisional arthroplasty can be considered (see Chap. 41). When a joint becomes ankylosed in a nonfunctional position, osteotomy can realign the limb.

Fig. 33.3 Tuberculous arthritis. (**a**) Knee joint involvement during later stages is evidenced by significant synovitis with effusion, which may be complicated by flexion contracture and posterior subluxation of the tibia. Plain radiographs demonstrate (**b**) osteopenia and (**c**) soft tissue swelling early in the disease process

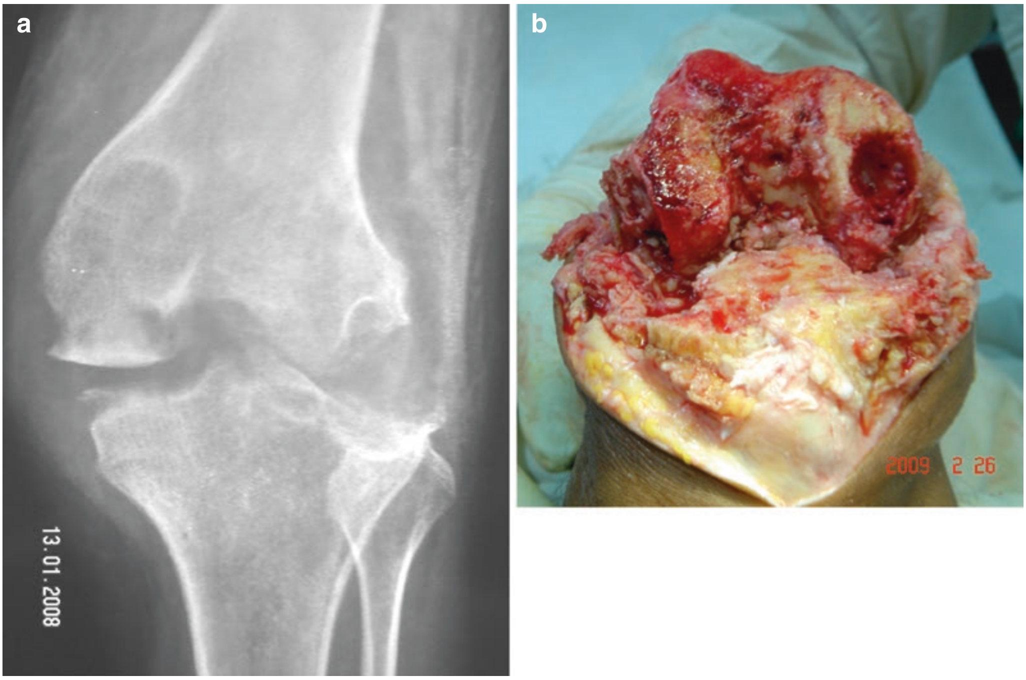

Fig. 33.4 (**a**, **b**) Proliferation of synovial granulation is followed by marginal erosions

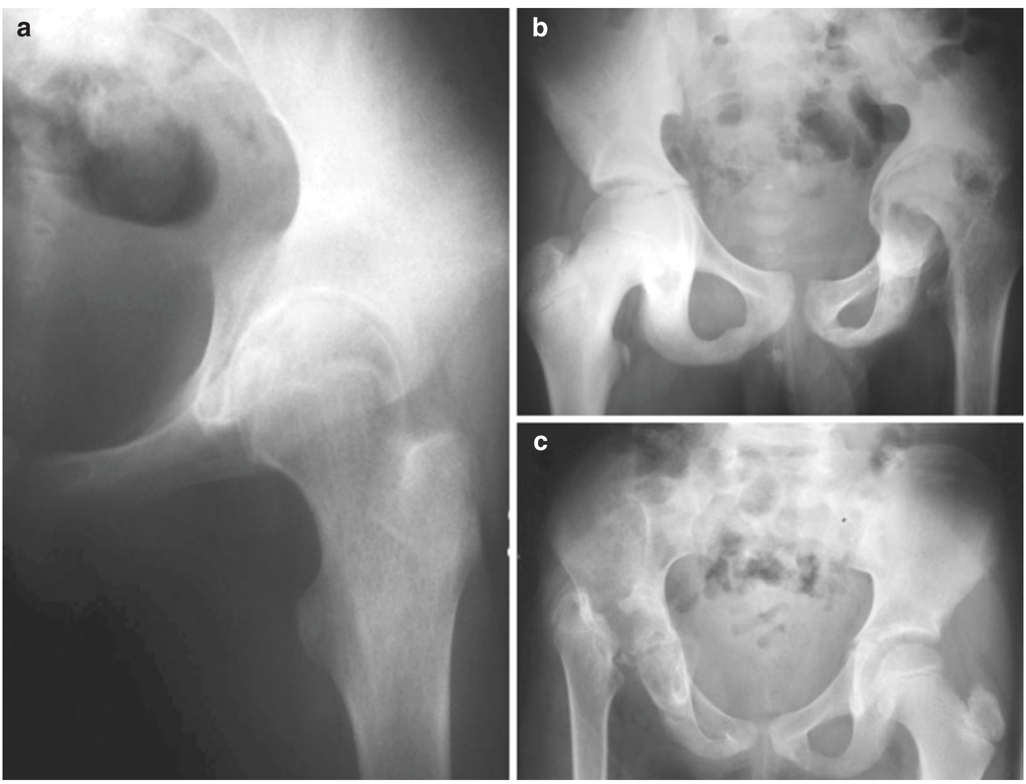

Fig. 33.5 Ultimately, there are destructive changes within the joint, for example, (**a**) narrowing of the joint space, (**b**) protrusion with destruction of the femoral head and acetabulum, and (**c**) loss of the femoral head and neck

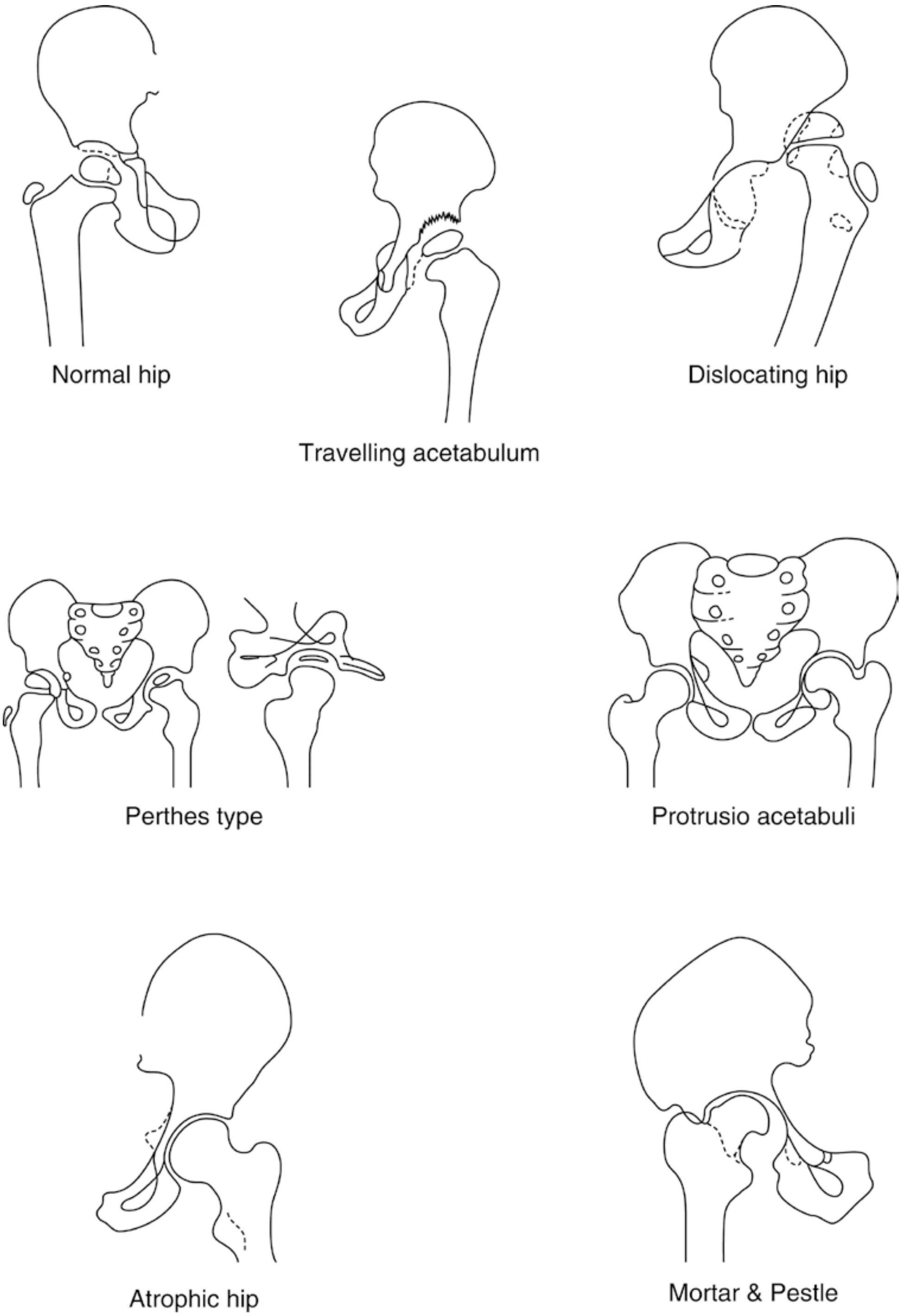

Fig. 33.6 Shanmugasundaram has classified the spectrum of morphologic abnormalities associated with hip disease. Generalized hyperemia, likely associated with a mild form of avascular necrosis, presents as the "Perthes" type in which there is coxa magna. Involvement of the acetabular roof is classified as a "traveling acetabulum," while the "protrusio" type occurs with lesions in the acetabular floor. Destructive changes on both the femoral and acetabular sides of the joint commonly result in joint incongruity "mortar and pestle." The "atrophic" subtype involves symmetric thinning of the joint space and may be confused with rheumatoid arthritis. The joint may also become dislocated, "dislocating" subtype

With hip involvement, the context will determine whether the goal is stability or motion. Hip arthrodesis can reliably reduce pain and restore alignment but produces increased stresses at the knee and lumbar spine that can lead to degenerative changes over the long term (Fig. 33.7a–d). Excisional arthroplasty will improve motion at the expense of stability, and the resulting gait disturbance can be significant. When the hip has autofused in a nonfunctional position and arthrodesis is an acceptable solution, an osteotomy can reposition the limb (Fig. 33.8a–d). Pelvic support osteotomy should be considered when retention of motion is desirable. When the resources are available, total joint arthroplasty is an option, along with prophylactic chemotherapy to reduce the risks of disease reactivation.

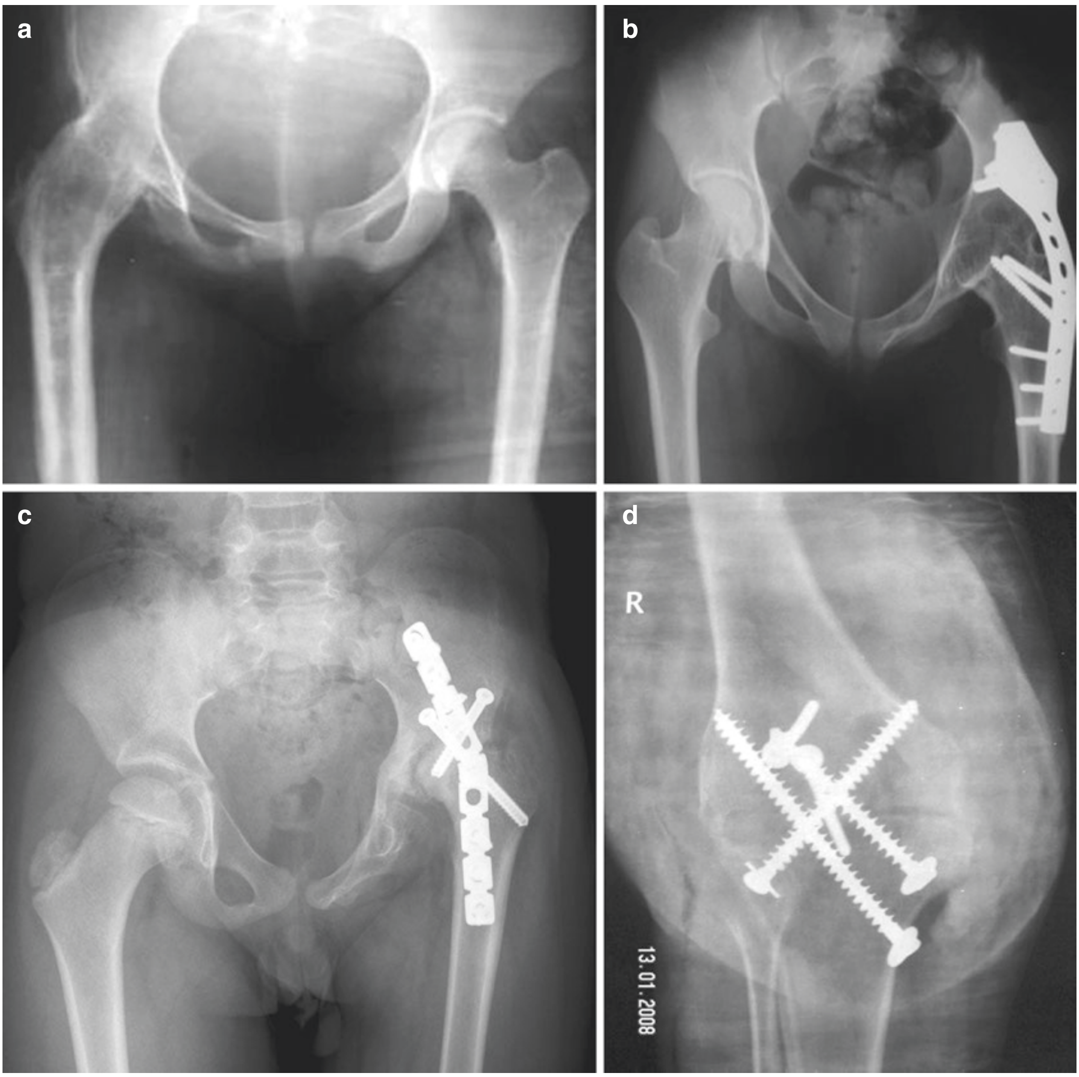

Fig. 33.7 Many options are available for salvage in the late stages of TB arthritis. (**a**) Arthrodesis provides excellent pain relief but may be undesirable depending on the demands of daily living. Arthrodesis of the hip can be achieved with debridement and spica cast application in younger children; fixation is required in adolescents and adults. (**b**) Internal fixation with a cobra plate via a posterior approach or (**c**) an anterior approach with screw and plate fixation. (**d**) This knee fusion was performed with screw fixation alone

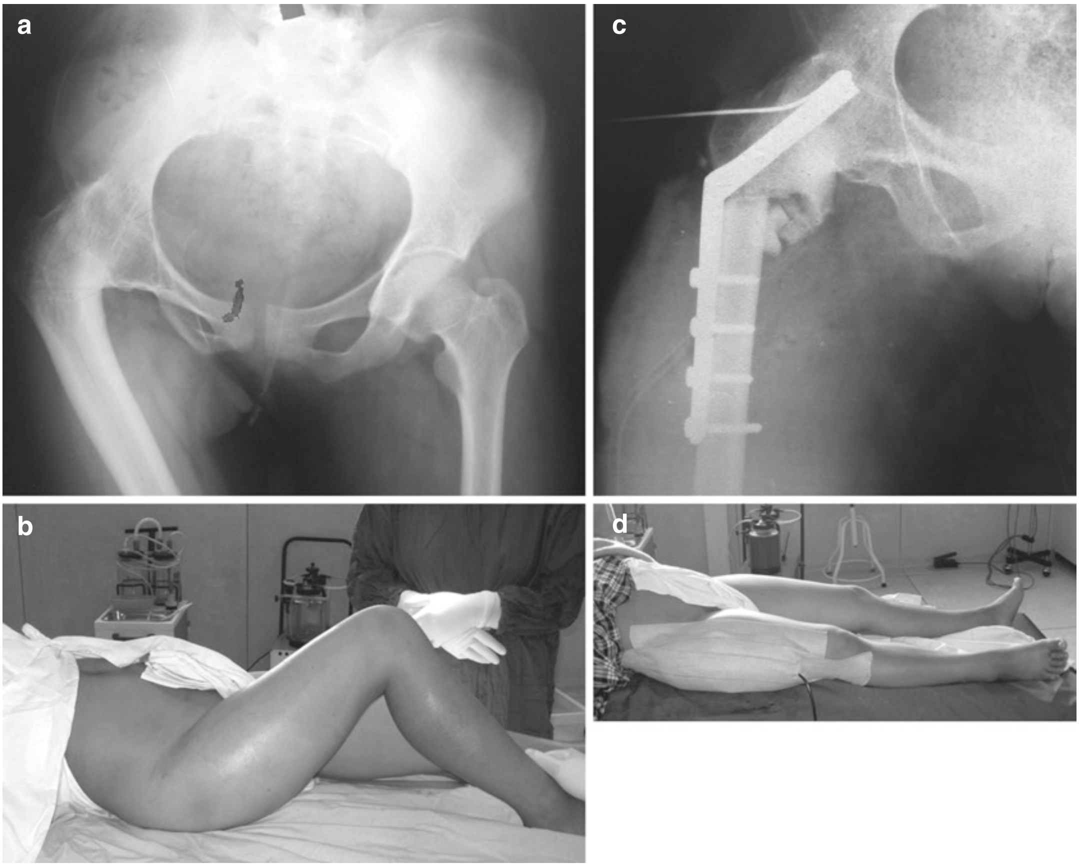

Fig. 33.8 (**a**, **b**) This adolescent presented with an awkward gait owing to spontaneous fusion of her right hip in severe flexion and adduction. (**c**, **d**) A realignment osteotomy was performed to place the extremity in a more favorable position. The inequality in limb lengths can be addressed at a later stage if her discrepancy is symptomatic

TB arthritis of upper extremity joints is uncommon. Involvement of the shoulder results in a fixed adduction contracture. Arthrodesis can eliminate pain and instability. Surgical treatment options for the elbow include synovectomy, but once destructive changes are present, excisional or fascial arthroplasty, or rarely arthrodesis (in a heavy laborer), may be required (see Chap. 41). Wrist involvement often spreads to the carpal bones and tendon sheaths, producing a flexion deformity. Early management includes splinting or immobilization. While synovectomy and debridement may be helpful before significant destructive changes have occurred in the wrist, most cases require arthrodesis for salvage.

Spondylitis

The spine is involved in approximately 50% of cases of osteoarticular TB. The main surgical concerns are preservation of neurologic function and prevention and treatment of kyphotic deformities. Much of the recent literature on this subject has come from centers with state-of-the-art capabilities, and the challenge is to adapt this knowledge to austere settings.

Pathophysiology and Natural History

Tuberculosis reaches the spine by hematologic dissemination from a pulmonary or genitourinary source, often through Batson's venous plexus, and commonly affects the thoracic or thoracolumbar spine. Direct extension from the lungs is rare. Three patterns of infection have been defined: paradiscal (most common), central, and anterior.

Bacilli lodge in the well-vascularized vertebral endplates and can spread beneath the anterior longitudinal ligament, the psoas sheath, or spinal canal, sparing the disk spaces early in the disease. While involvement of the anterior portions of the vertebral bodies results in multilevel spinal abscesses, involvement of the central portion of the vertebra can lead to loss of anterior column support and progressive collapse into kyphosis. Isolated posterior involvement is rare, as is panvertebral disease. Loss of stability may occur due to pathologic fracture or circumferential disease. Cold abscesses can present as a soft tissue mass in the axilla (Fig. 33.9), flank, groin, or buttock and spontaneously exit the skin as a sinus.

Fig. 33.9 This adult female developed a swollen lump in her left axilla that is mildly erythematous and non-tender. It proved to be a cold abscess from spinal tuberculosis

The natural history of spinal disease is described in three stages [6]. Stage one lasts from 1 to 12 months. The second stage may last up to 3 years and is characterized by abscess formation and bony destruction. The third or healing stage occurs when the vertebrae ankylose (Fig. 33.10). Approximately 30% of patients do not survive to this last stage. Nonunion suggests either recurrence of active disease or superinfection by pyogenic bacteria, both of which are associated with an unfavorable outcome.

Ten percent of patients present with neurologic involvement, most commonly Pott's paraplegia [7]. Cord compression in "early-onset" paraplegia is due to pus, granulation tissue, and/or sequestrae. In contrast, "late-onset" paraplegia is most often due to direct bony compression over the sharp internal gibbous, calcified caseous material or fibrous tissue bands around the spinal cord. The prognosis is much better for early-

Fig. 33.10 This teenager was treated medically for TB but developed a severe kyphosis, with progressive collapse and fusion at the apex

onset paraplegia, except when there is direct dural invasion. A kyphotic deformity may progress despite successful treatment of active disease, even after skeletal maturity, and lead to paraplegia.

Patient Evaluation

Back pain is the most common presenting symptom and is generally less severe when compared with pyogenic spondylitis. The pain follows an indolent course, often increasing noticeably at night and becoming gradually worse as the spine becomes mechanically unstable. Gait changes and subtle neurologic abnormalities due to myelopathy can be seen at the time of presentation. Constitutional symptoms are often present. The physical examination should include a meticulous neurologic examination; skin examination for masses, cold abscesses, enlarged lymph nodes, or sinuses; and the evaluation of spinal alignment.

Highly elevated white blood cell counts, CRP levels over 5 mg/dl, ESR levels over 40 mm/h, and levels of alkaline phosphatase (ALP) over 120 IU/l are more commonly associated with pyogenic spondylodiscitis, while the laboratory results for TB are both less marked and specific. This makes a high index of suspicion based on the presence of active TB of other organs, a history of longer diagnostic delays, and involvement of more than three spinal levels important in the differential diagnosis [8].

The radiographic differential diagnosis includes brucellosis, atypical mycobacteria, fungal, pyogenic discitis, vertebral osteomyelitis, and both primary and secondary spinal tumors. Plain radiographs are usually all that are available in austere settings.

Generally, two or three spinal levels are involved, and noncontiguous sites are reported. Localized osteopenia is the first sign and may be associated with loss of definition at the vertebral endplates. The disk space is commonly preserved early in the disease but becomes obliterated later. Scalloping of multiple anterior aspects of vertebral bodies, aneurysmal syndrome, can be observed. A loss of vertebral body height commonly occurs due to tissue destruction and collapse (Fig. 33.11). Radiologic findings suggestive of an abscess include fusiform soft tissue swelling (Fig. 33.12) or asymmetry or loss of the psoas shadow.

Destruction of the anterior vertebrae at multiple levels leads to a progressive kyphosis (Fig. 33.13a–c). Factors influencing kyphotic development include thoracic location, pediatric patients, and the pretreatment angle of kyphosis (Cobb angle). Rajasekaran et al. have identified four radiological features that may predict progression of kyphosis: (1) facet dislocation, (2) lateral translation, (3) retropulsion of the vertebral body, and (4) toppling of one vertebra over another [9, 10] (Fig. 33.14). They suggest that two or more findings require stabilization. Multilevel involvement with disk space sparing is seen with metastatic disease; however there are no paraspinal abscesses. It is difficult to distinguish tuberculous spondylodiscitis from that caused by atypical mycobacteria or fungi on radiologic and clinical findings alone.

Although rarely available in the settings where spinal TB is most common, MRI remains the most valuable imaging modality, showing abscess formation (Fig. 33.15a–d) and the involvement of structures around the spine. MRI is also the only modality that helps distinguish spondylitis of different etiologies.

Treatment

The goal of the treatment is to eradicate the disease, prevent or treat any deformity, and preserve or improve neurologic function. The prognosis depends on the timing of diagnosis and the efficacy of treatment.

Outpatient chemotherapy is as effective as surgical debridement in uncomplicated cases [11], even those with stable, mild paraparesis. There is no added benefit from bed rest or immobilization, as these are ineffective in preventing deformities when instability is already present. Adequate medical management may not prevent kyphotic deformities and the cosmetic, func-

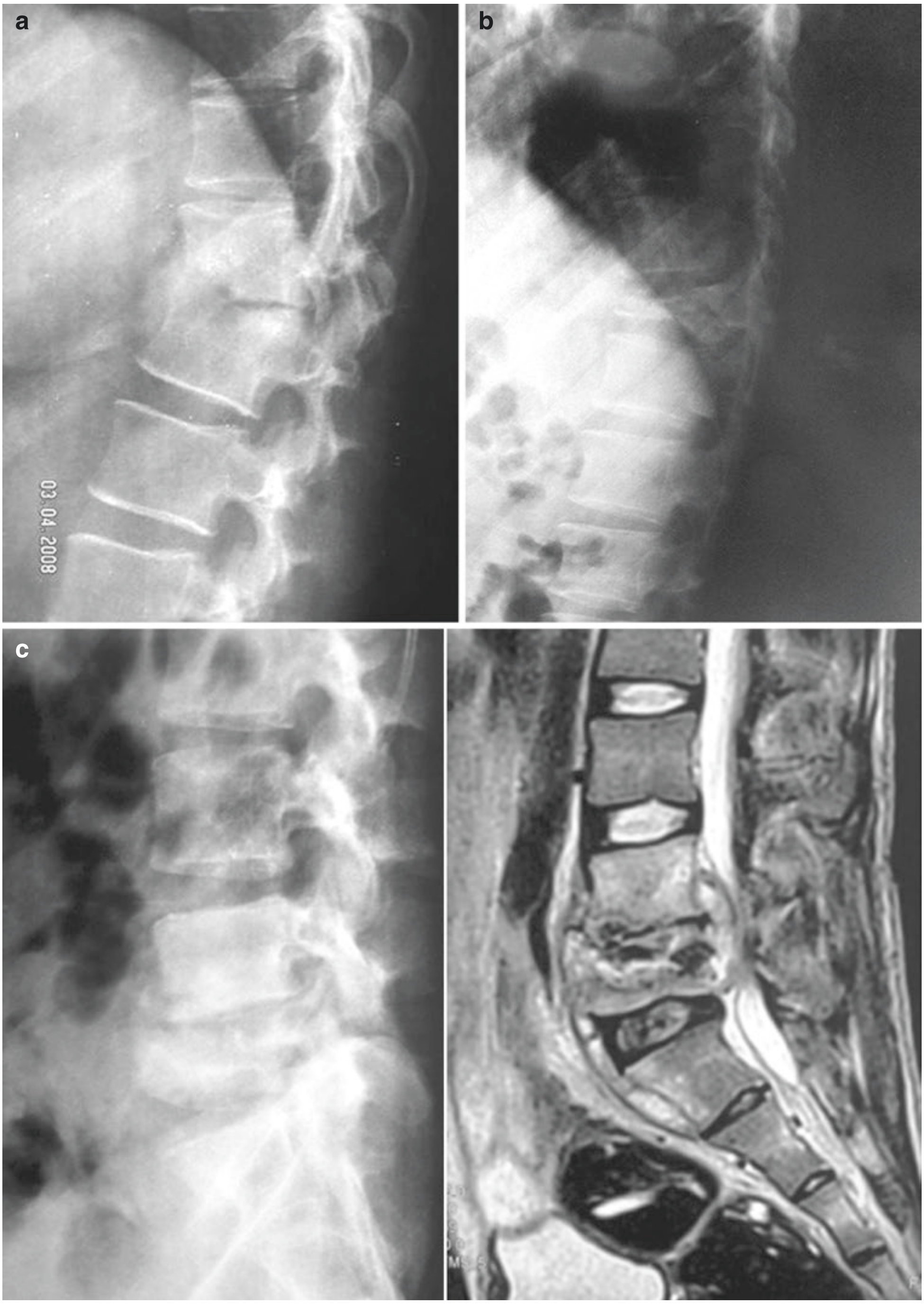

Fig. 33.11 (**a**) TB of the spine usually involves the anterior portion of the vertebra. Inflammation and bony resorption predispose to a progressive kyphotic deformity. (**b**) In some patients the central portion of the vertebra is more involved, resulting in central collapse, giving the appearance of vertebra plana. (**c**) Collapse of the L4 vertebra into L5 (plain radiograph on *left*, MRI on *right*), with the MRI demonstrating abscesses and retropulsion of debris/caseous material

tional, and neurologic complications that follow. Radiographic changes can progress for more than a year after treatment is started and should not be mistaken for the failure of medical treatment.

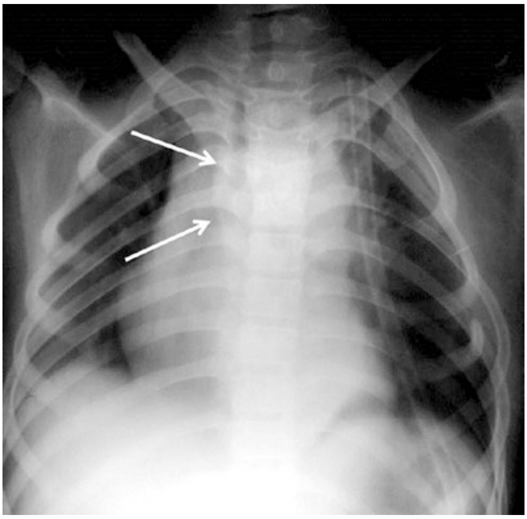

Fig. 33.12 Thoracic paraspinal abscesses appear as oval soft tissue densities adjacent to the spine on a chest radiograph (*arrows*), sometimes with calcifications within the wall of the abscess

Surgical treatment is reserved for establishing the diagnosis and treating complications of the disease, such as progressive or profound neurologic deficits, or patients with or at high risk for progressive kyphotic deformity. In the past surgical treatment for TB spondylitis consisted of thorough debridement of necrotic tissue; decompression of the neural elements; microbiologic assessment of specimens, if not done previously; and stabilization by instrumentation and fusion. Though stabilization can be accomplished using a variety of approaches (Table 33.1), in the last 10 years, there has been a shift toward posterior-only procedures, even with extensive bone destruction and/or deformity (Fig. 33.17a–c). The posterior approach offers less morbidity and independence from requiring other specialties providing exposure. The original "Hong Kong" procedure that involved anterior debridement and strut grafting (Fig. 33.16a–e), to restore anterior column integrity, is used less commonly since the introduction of three-column fixation through transpedicular screws, and pure anterior approaches have been largely abandoned.

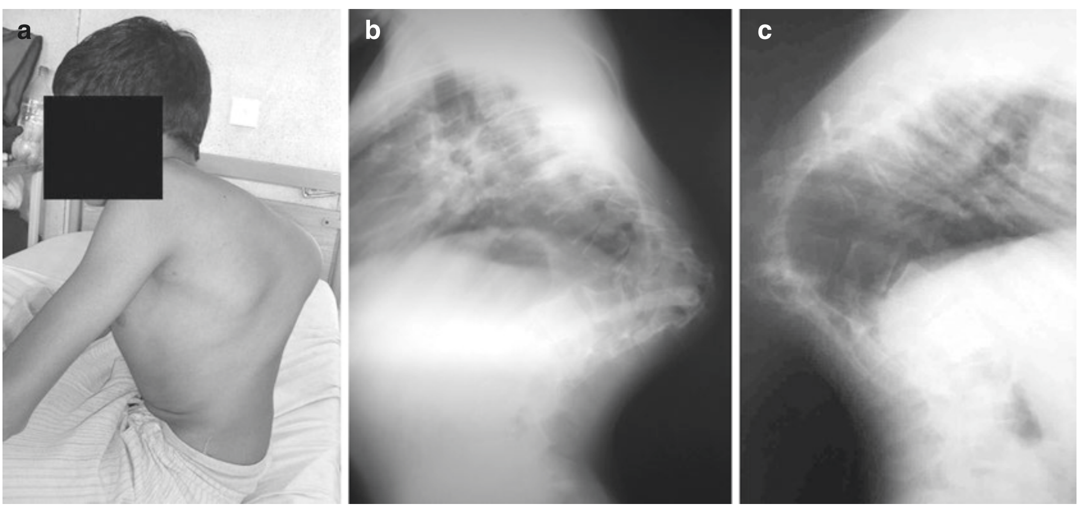

Fig. 33.13 (**a**–**c**) The treatment of severe kyphotic deformities is technically difficult, and treatment is associated with a high risk of complications, especially in patients with "healed disease"

Fig. 33.14 This child developed spinal instability, including two of the four Rajasekaran criteria, lateral vertebral translation and "toppling over"

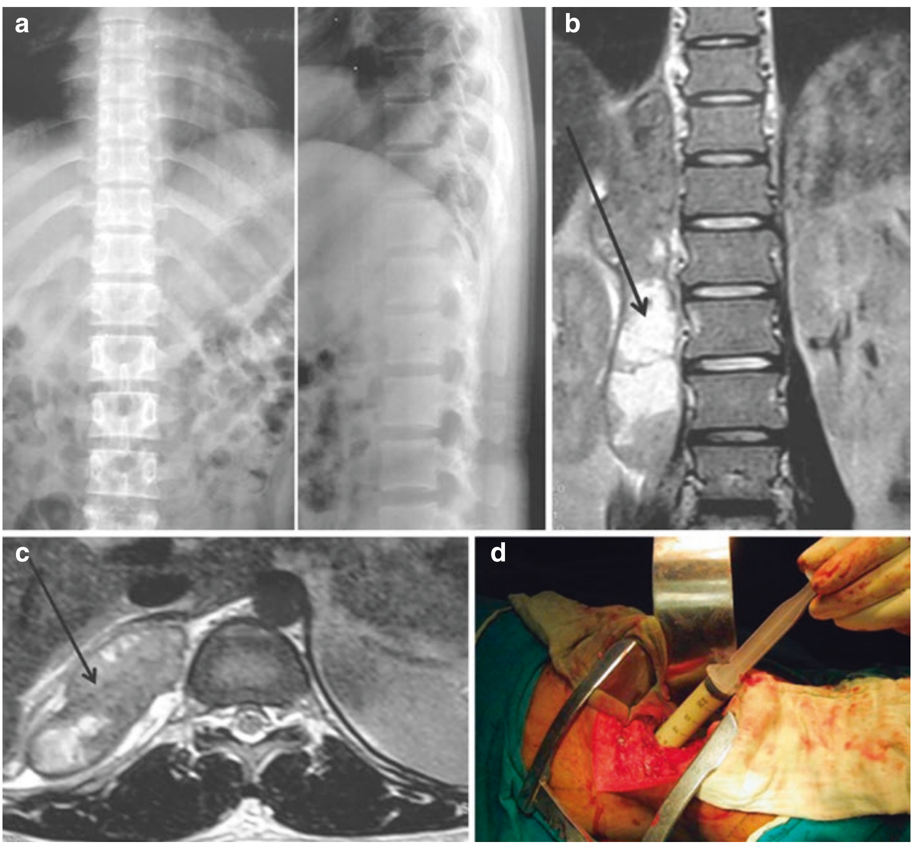

Fig. 33.15 (**a**) This patient had no evidence of an abscess or bony destruction on plain radiographs; however (**b**, **c**) an MRI scan revealed a large abscess adjacent to the lumbar spine, *arrows*. (**d**) An extraperitoneal approach was used to drain the abscess

Table 33.1 Surgical procedures used in the treatment of spinal tuberculosis

Surgical procedures	Indications/advantages	Disadvantages
Costotransversectomy	Abscess drainage in medically debilitated patients	Cannot decompress or perform an arthrodesis
	Less morbidity	
Lateral extrapleural approach (extracavitary)	Decompression and fusion Extrapleural	Greater challenge if instrumentation is planned
Anterior decompression and fusion with or without instrumentation	Direct visualization	Requires thoracotomy and/or taking down of the diaphragm
	Can perform wide decompression or debridement	Higher risk graft failure/nonunion if >2 segments spanned disk spaces and no instrumentation
	Does not destabilize posterior structures	Difficult to visualize apex in sharp angular kyphosis
Anterior and posterior decompression and fusion	Circumferential disease	Higher morbidity and/or risk of complications
Posterior spinal fusion followed by anterior spinal decompression and fusion	Neurologically normal with high risk of future deformity progression stabilize prior to debridement and grafting	Two stages required
Isolated posterior spinal fusion	Mild kyphosis with significant growth remaining	Posterior tethering, gradual restoration of alignment (reduction in kyphosis) with continued anterior spinal growth
Laminectomy	Isolated disease of posterior elements (rare) extramedullary or intradural disease	Risks destabilizing the spine if there is anterior column involvement
Posterior approach for debridement, grafting, and instrumentation	Eliminates need for anterior procedure	Technically demanding
	Shortens the spine	Higher risk of complications
Anterior +/− posterior release, traction, then instrumentation/fusion	Severe deformities with healed disease	High risk of complications
		Three to four procedures required
		Resource intensive
Resection of internal gibbus (apex of kyphotic deformity)	Severe deformities with healed disease, neurologic dysfunction	Very high risk of complications such as paralysis or neurologic deficit

Most surgeons prefer a posterior stabilization extending two to three segments above and below the pathology. In cases where bone destruction is not extensive and only drainage is required, an ultrasound or CT-guided biopsy can be followed by posterior instrumentation and fusion if instability is suspected. Good results have been reported with effective chemotherapy and the posterior-only approach without extensive debridement, calling the need for debridement into question [12]. Some authors have suggested a posterior approach initially, reserving the anterior approach only for patients who fail to improve. In the setting of neurologic deficit, posterior decompression in the form of laminectomy should be considered (Wang et al.). Posterior trans-pedicular instrumentation also appears to provide better correction and maintenance of kyphosis [13].

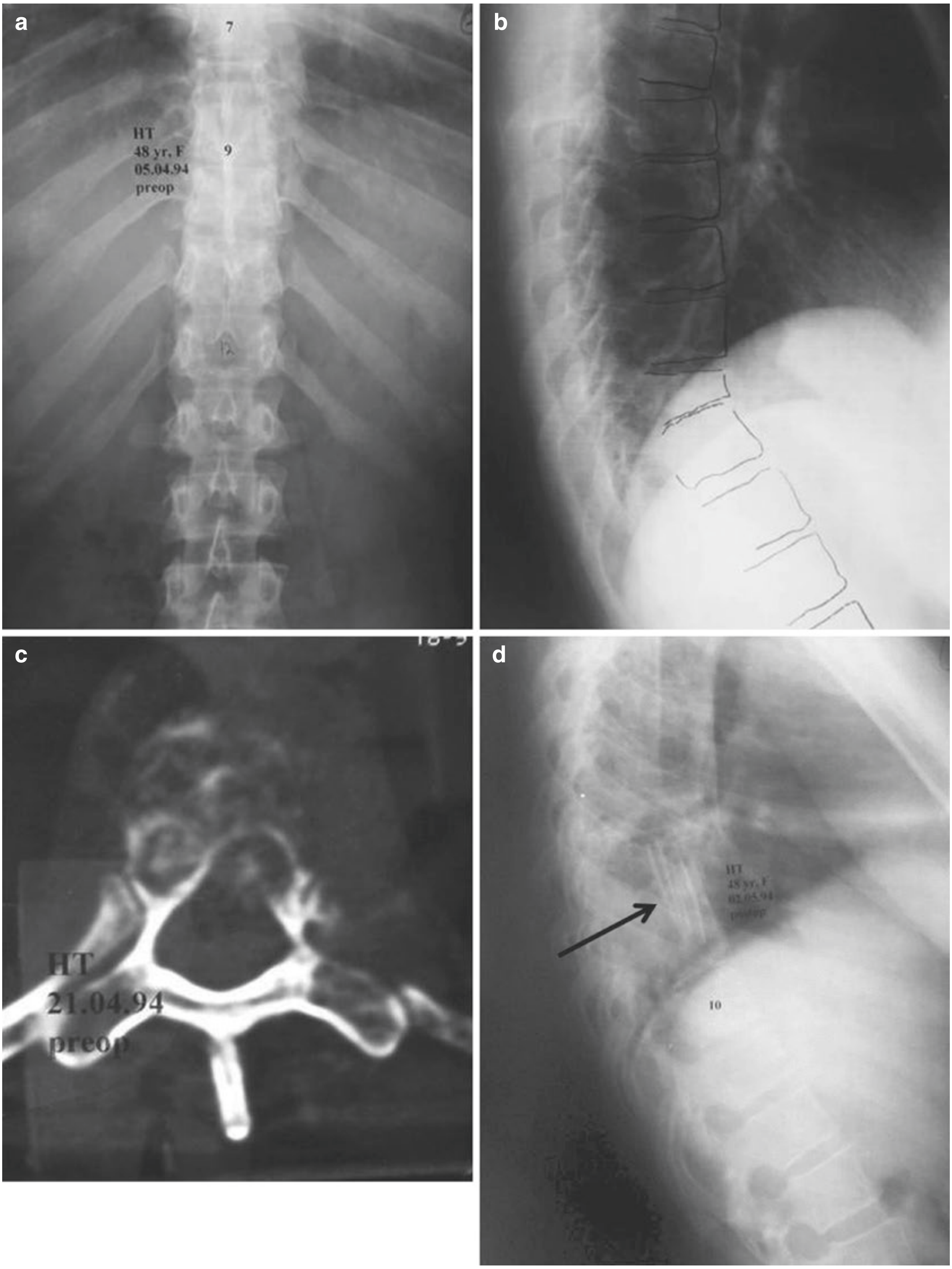

Fig. 33.16 Hodgson and colleagues popularized the anterior debridement and strut grafting for spinal tuberculosis. (**a**–**c**) This adult patient initially had involvement at three adjacent levels with mild collapse at a single level and (**d**, **e**) was treated by the Hong Kong procedure. Several strut grafts (*black arrows*) were placed from T8-T9, across the diseased vertebrae, following spinal cord decompression and debridement of abscess and bony debris

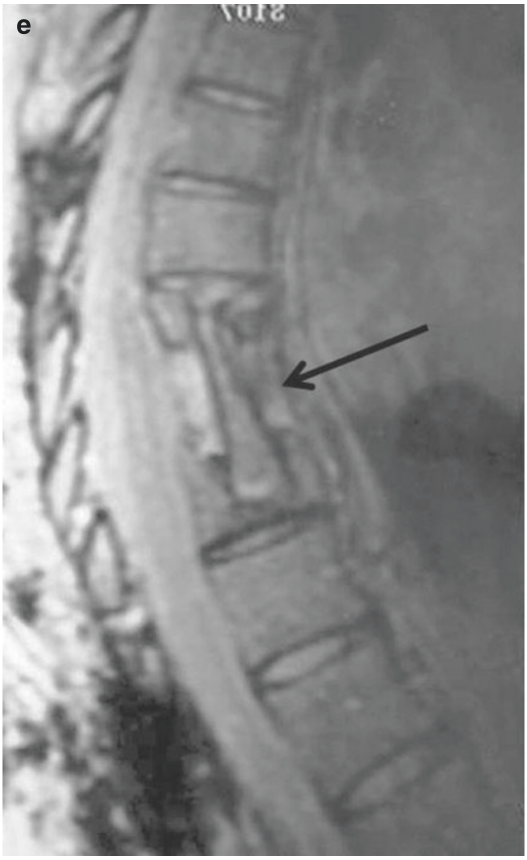

Fig. 33.16 (continued)

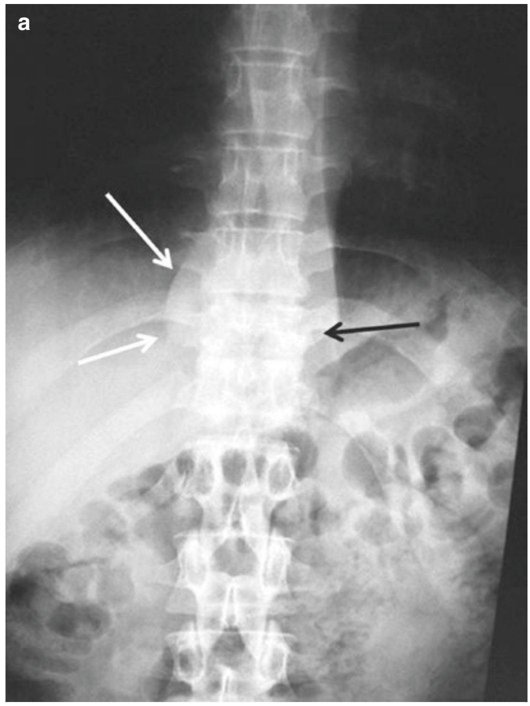

Fig. 33.17 (**a**, **b**) This 24-year-old male had severe collapse of a lower thoracic vertebra with relative preservation of the superior and inferior disc spaces (*black arrow*), a paraspinal abscess (*white arrows*), and was (**c**) treated by a posterior-only approach involving decompression/debridement, placement of a cage for anterior column support, and segmental posterior instrumentation extending two vertebrae above and two below the involved vertebra

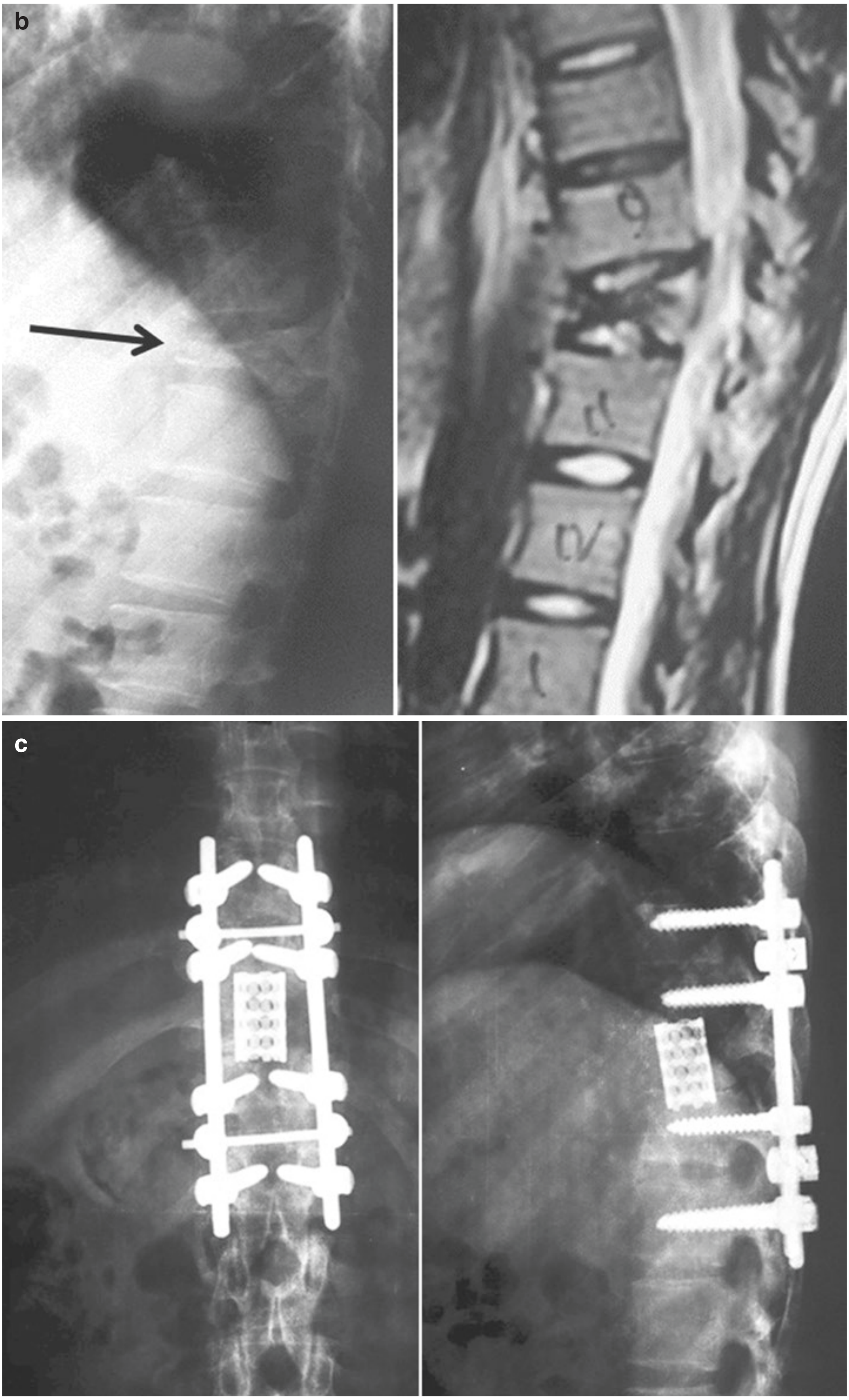

Fig. 33.17 (continued)

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Part VI

Non-infectious Pediatric Conditions

34 Clubfoot Etiology, Pathoanatomy, Basic Ponseti Technique, and Ponseti in Older Patients

Alaric Aroojis, Shafique Pirani, Bibek Banskota, Ashok Kumar Banskota, and David A. Spiegel

Introduction

Clubfoot or congenital talipes equinovarus (CTEV) is a hindfoot deformity caused by malalignment at the talocalcaneonavicular complex (Fig. 34.1) with a worldwide incidence of approximately 1 in 1000 live births.

Clubfoot can be classified as idiopathic, postural, syndromic, or neurologic. The etiology of idiopathic clubfoot is debated, but the weight of evidence suggests a genetic etiology, though the inheritance pattern is unclear. A postural clubfoot is due to intrauterine positioning and either resolves spontaneously or is easily treated by gentle manipulation or several casts. Syndromic clubfoot is seen in association with a variety of conditions including arthrogryposis multiplex congenital, early amniotic rupture sequence/constriction band syndrome, and skeletal dysplasias, while the neurologic type is due to conditions such as myelomeningocele. Clubfoot associated with syndromic and neuromuscular conditions tends to be more rigid and difficult to treat compared with idiopathic clubfoot.

Pathoanatomy

The pathoanatomy of clubfoot primarily involves abnormalities in the talocalcaneonavicular complex with the calcaneus and navicular rotating around the talus. Both intraosseous (morphologic) and interosseous (alignment) abnormalities are accompanied by soft tissue contractures. Alignment abnormalities are illustrated in the model in (Fig. 34.2a, b). Clinical findings include (1) midfoot cavus, (2) forefoot adductus, (3) hindfoot varus, and (4) hindfoot equinus (CAVE) (Fig. 34.2c).

The talus in clubfoot is smaller than normal, with medial and plantar deviation of the head

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Fig. 34.1 (**a**) An ambulatory child with untreated clubfoot. (**b**)Walking on the lateral border of the foot can lead to excessive shoe wear and skin breakdown. (Photo courtesy of J. Norgrove Penny)

and neck. The anteromedial surface of the head articulates with the navicular, while the anterolateral surface is uncovered. Paradoxically, the talus is externally rotated within the ankle mortise. The calcaneus is adducted and inverted under the talus with dysplastic facets, while the sustentaculum tali is underdeveloped. The navicular is flattened and medially displaced relative to the talar head and in severe cases articulates with the medial malleolus. The cuboid is medially displaced and inverted relative to the talus, with obliquity at the calcaneocuboid joint in which the medial corner of the joint is proximal to the lateral. At the ankle joint, the tibia articulates only with the most posterior part of the talus, and in severe deformities the posterior tuberosity of the calcaneus may touch the posterior surface of the tibia.

Soft tissue contractures accompany these abnormalities in bony morphology and alignment. The musculotendinous units of the deep posterior compartment (tibialis posterior, flexor digitorum longus, and flexor hallucis longus) are contracted, while the muscles and tendons of the anterior and lateral compartments (tibialis anterior, peroneus longus, and brevis) are elongated. The heel cord is thickened and contracted and is inserted slightly medially on the calcaneus. Multiple soft issue contractures are observed including the deep plantar muscles of the foot, the abductor hallucis, and the posterior tibiotalar, talofibular, calcaneofibular, deltoid, and spring ligaments.

Basic Ponseti Technique

The aim of clubfoot treatment is to obtain a functional, pain-free, plantigrade foot with adequate mobility. The available evidence suggests that while clubfeet treated by both the Ponseti method and extensive soft tissue releases have limited range of motion, reduced strength, and residual deformities, feet treated by the Ponseti method have greater strength and range of motion, fewer degenerative changes, less need for additional surgical procedures, and better functional out-

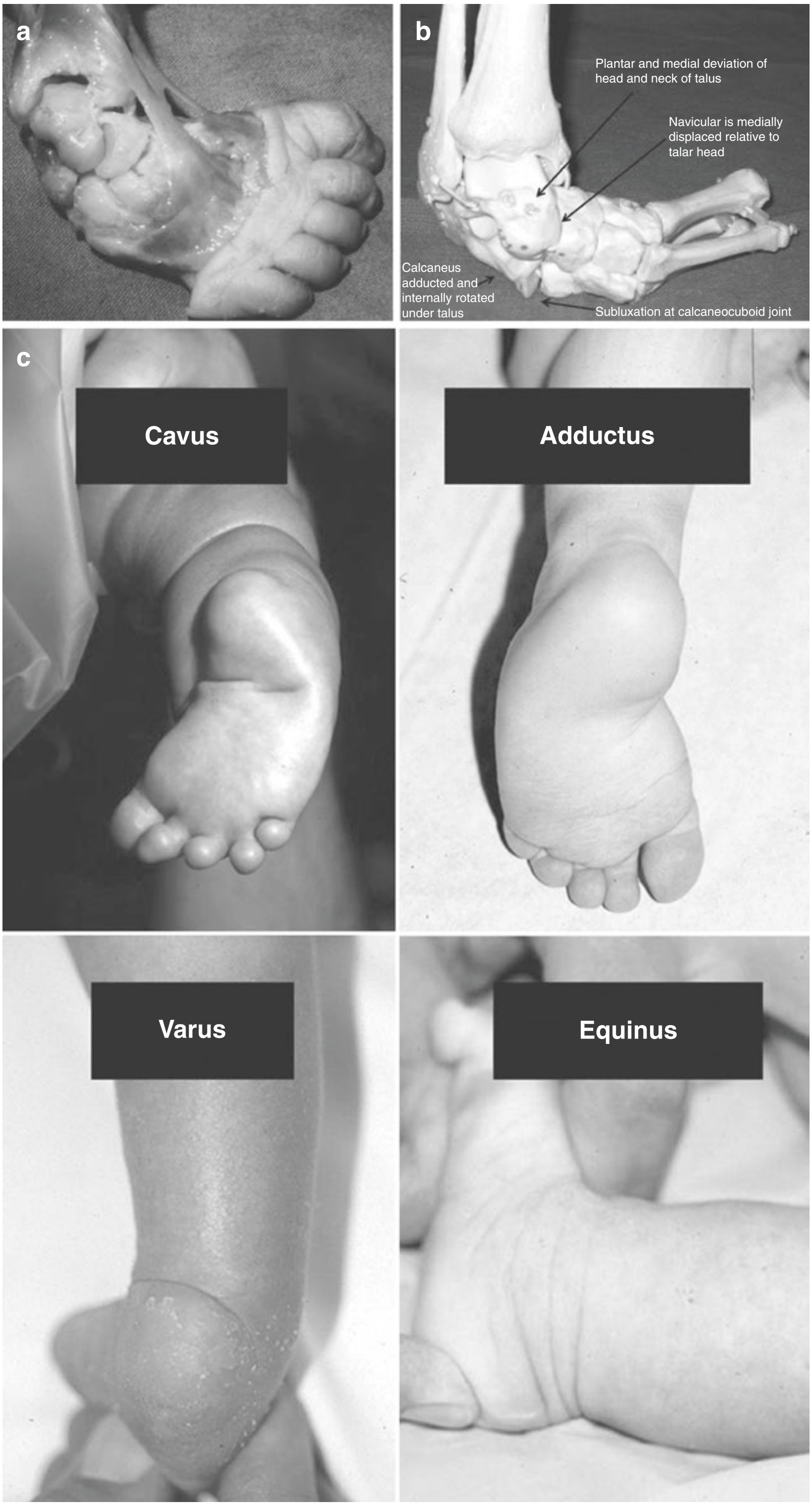

Fig. 34.2 Clubfoot is a hindfoot deformity involving malalignment between the talus, calcaneus, and navicular. (*Congenital Clubfoot, Fundamentals of Treatment* by Ponseti () Fig. 34.9a p. 18. By permission of Oxford University Press). (**a**, **b**) Osseous components of the deformity are illustrated on this model. (**c**) Clinical components of the deformity include cavus (midfoot), adductus (midfoot), varus (hindfoot), and equinus (hindfoot)

comes. The method is now practiced to some extent in more than 100 countries.

The Ponseti method of serial casting with percutaneous tendoachilles tenotomy is described as extra-articular and "minimally invasive" rather than nonsurgical. Long-term bracing is essential to maintain the correction. Treatment is ideally started shortly after birth. Evidence from programs encompassing all ranges of economic development suggests that task shifting or sharing can be employed as non-orthopedic or even nonmedical caregivers can be trained to apply the casts.

It is preferable to have the child relaxed by feeding immediately prior to and during casting. With the patient supine in the mother's lap, the person manipulating the foot stabilizes the leg at or above the malleoli without touching the calcaneus. There are two common hand positions (Fig. 34.3). In the first, the index finger puts pressure on the lateral side of the talar head, while the tip of the thumb elevates the first ray and abducts the forefoot. In the second hand position, the thumb puts pressure on the lateral side of the talar head while the index finger dorsiflexes the first ray and abducts the foot. Because the navicular is medially displaced with its tuberosity almost in contact with the medial malleolus, one can feel the prominent lateral part of the talar head as the first bony prominence, just anterolateral to the lateral malleolus. An assistant is helpful in stabilizing the foot and upper thigh.

The talus serves as a fixed fulcrum, while the malalignment is corrected by rotating the hindfoot bones around the talus (Fig. 34.4a). In the initial cast, the first metatarsal is dorsiflexed to correct the cavus (Fig. 34.4b). This supinates the forepart of the foot and aligns the forefoot with the hindfoot, which remains in varus. Progressive abduction of the foot is used to simultaneously correct

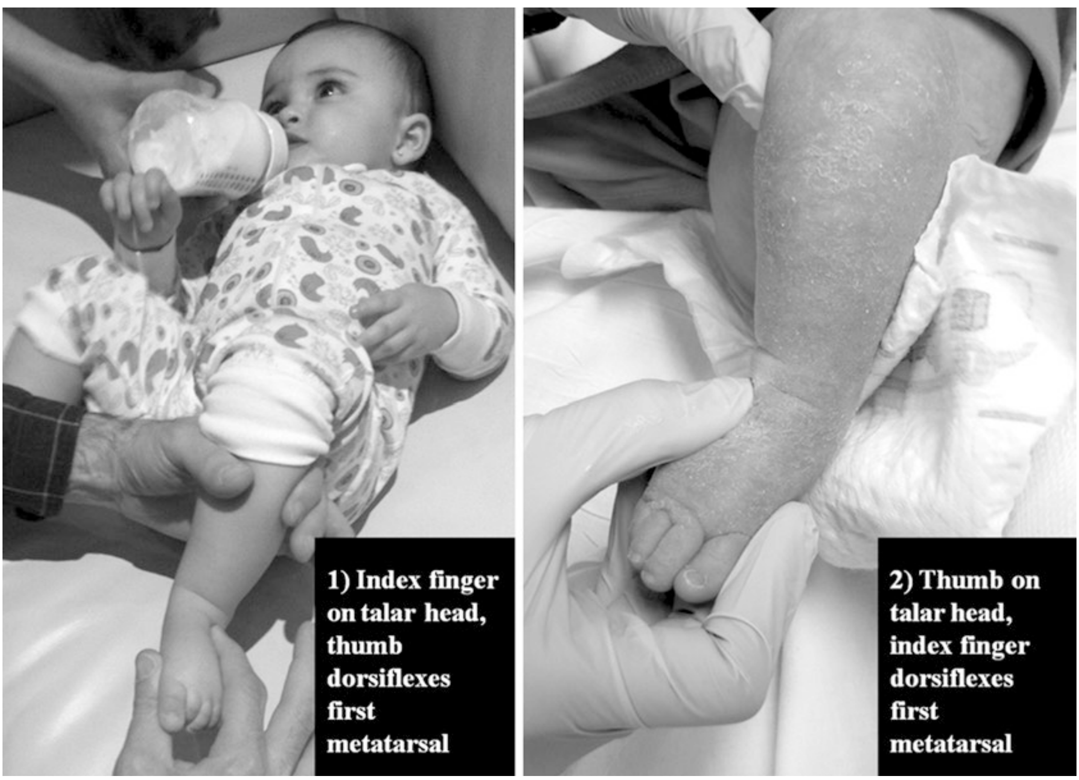

Fig. 34.3 Two different ways to hold the foot while applying the cast. The diaper should always be removed when applying the plaster to ensure that the cast will extend up to the groin

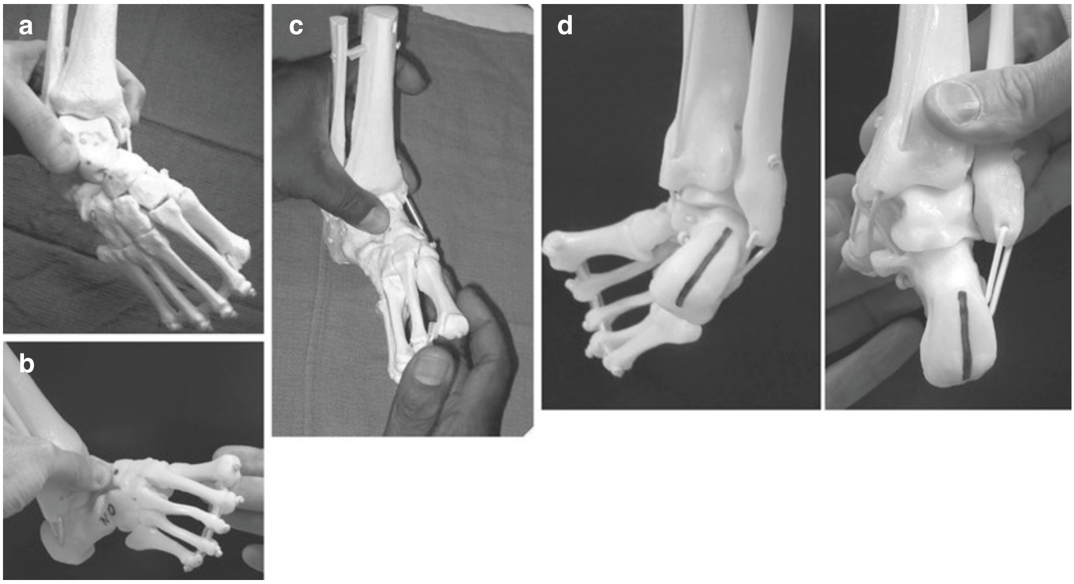

Fig. 34.4 (**a**) The talus must be fixed in space during manipulation and casting. (**b**) The first metatarsal is elevated to correct the midfoot cavus, and the (**c**) forefoot is abducted while maintaining pressure on the talus. (**d**) Abduction simultaneously corrects adduction and varus, note the eversion of the calcaneus and the correction from varus to valgus

adductus and varus (Fig. 34.4c, d). The foot should never be pronated as this increases the cavus and locks the calcaneus in varus. Once full abduction is achieved, the ankle equinus is corrected, usually by a percutaneous tenotomy. Long leg casts are used in all stages of casting (Fig. 34.5).

During the next several casts, care is taken to keep pressure on the lateral talar head during manipulation and casting; otherwise the talus will rotate laterally as the foot is abducted, pushing the lateral malleolus posteriorly, resulting in spurious correction. The foot is maintained in mild plantar flexion during this initial series of casts, leaving correction of equinus until later castings.

Initially, a below-knee cast is applied. After molding is completed, the cast is extended above the knee to the groin. Short leg casts do not hold the calcaneus abducted, allowing the foot to slip within the cast. The cast should be removed at the time of cast change and not the night prior. Dr. Ponseti believed the gains in contracture resolution achieved by the cast could be partially lost, adding more total time to the casting. Soaking and unwrapping the plaster by the parent is more child-friendly than using a cast saw or cast knife (Fig. 34.6). The parents are taught to keep the plaster dry and clean and to examine the toes for any pallor or discoloration that might indicate the cast is too tight.

The goal of casting is 70° abduction—usually requiring three to six casts. Once this is achieved and the heel is in valgus, the residual equinus is addressed. Attempts to correct the equinus before heel varus and forefoot supination are corrected will result in a rocker-bottom deformity. Avoid external rotation of the tibial axis, which can achieve spurious correction by pushing the lateral malleolus posteriorly.

A tenotomy of the tendoachilles is required to correct residual equinus (ankle dorsiflexion <10°) in approximately 90% of patients once the other components of the deformity are corrected (Fig. 34.7). The tenotomy can be performed under local in the outpatient clinic in infants, but walking aged patients may require ketamine or general anesthesia. The ankle is dorsiflexed by

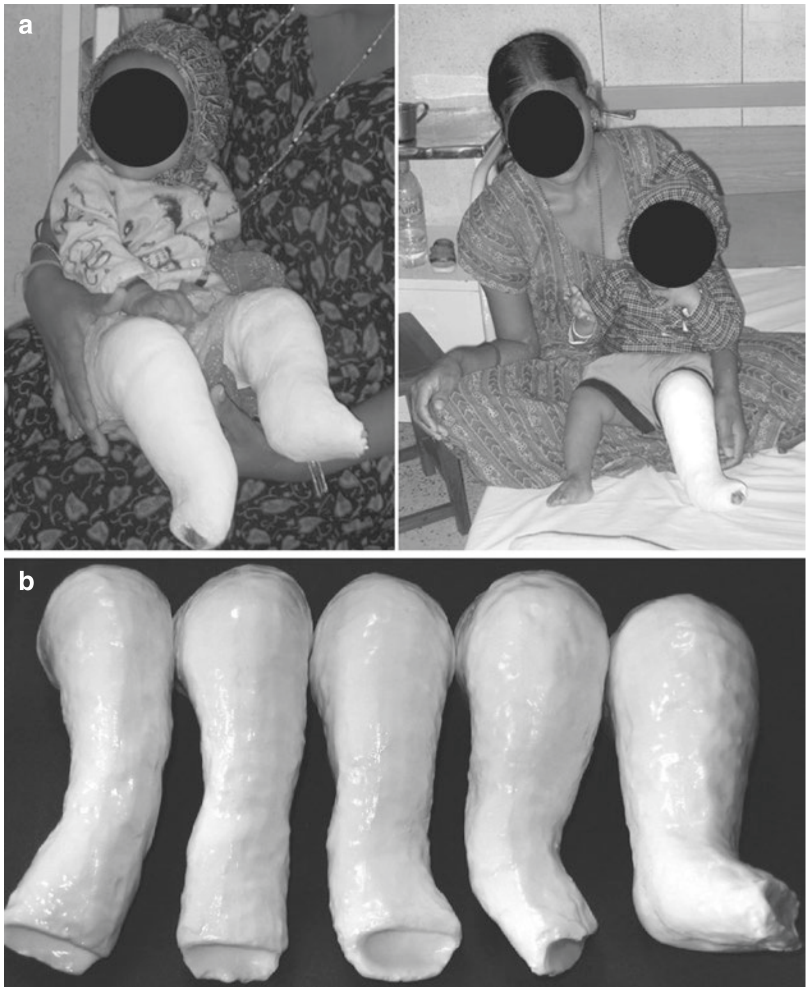

Fig. 34.5 (**a**) Long leg casts are applied with the foot (**b**) progressively abducted. Once full abduction is achieved, equinus is treated by casting or tendoachilles tenotomy. (Reprinted with permission from Ponseti ())

Fig. 34.6 The cast can be removed by first soaking in warm water and then gently unrolling the wet plaster

the assistant with the knee in extension, making the tendon taut so it is easily palpated. The scalpel blade is introduced approximately 1 cm above the calcaneal insertion and directed from medial to lateral. The blade is turned 90° to lie horizontally on the anterior surface of the tendon, making the tenotomy from inside to out. A sudden pop is felt along with an increase in dorsiflexion. A dressing and compression bandage are applied, and the child is immediately handed to the mother for feeding. Once the child becomes pacified and the bleeding stops, a toe-to-groin cast is applied with the foot in maximum dorsiflexion (usually 15° or more but never normal) and 60° abduction.

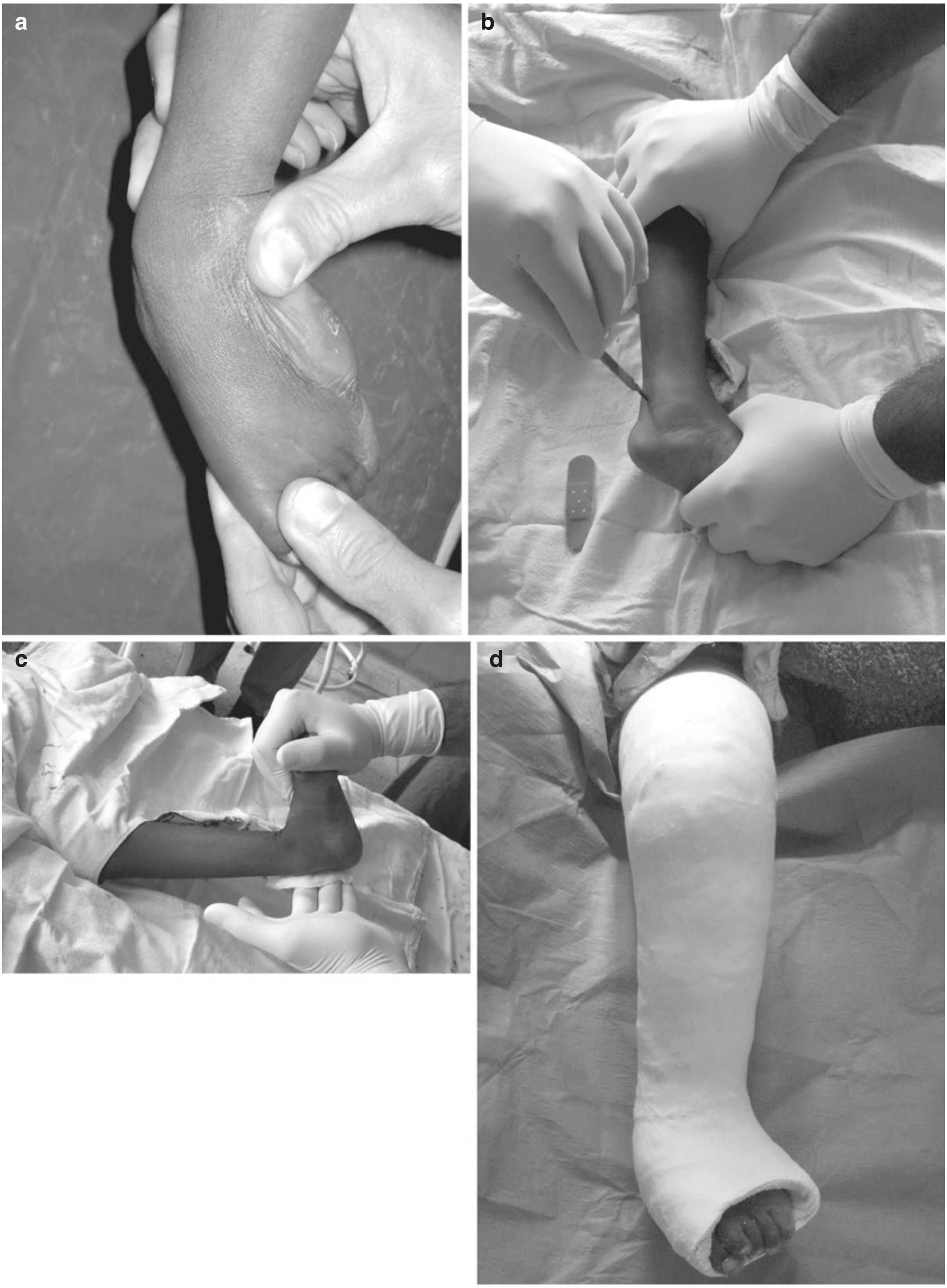

Fig. 34.7 (**a**) Before a percutaneous Achilles tenotomy is considered, the hindfoot must be able to be positioned in valgus with full passive abduction. (**b**) The tenotomy is performed with an assistant dorsiflexing the foot to maintain tension on the tendon. (**c**) Dorsiflexion after the tenotomy. (**d**) The toe-to-groin cast is worn for 3 weeks

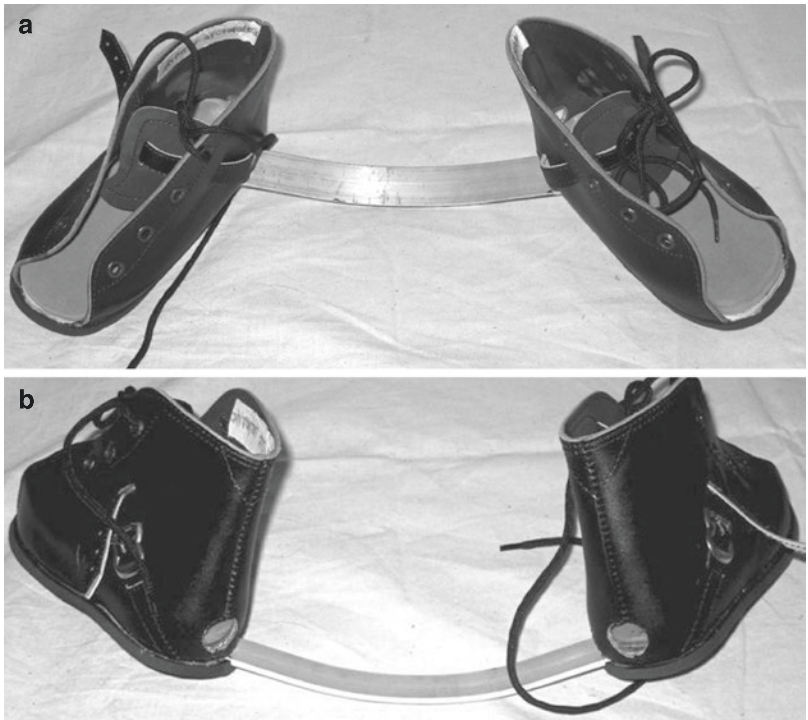

Fig. 34.8 (**a**, **b**) A foot abduction orthosis. Note the round window at the heel, so parents can confirm that the heel is properly seated in the brace

This cast is worn for 3 weeks, after which an abduction orthosis is applied.

Though rare, if less than 15° dorsiflexion is achieved, several additional casts can be applied to increase dorsiflexion. Adding a posterior ankle and/or subtalar release may increase dorsiflexion acutely, but the improvement is usually temporary, and scarring of the posterior structures predisposes to re-contracture. Revision tenotomies are indicated in cases of equinus relapse.

Bracing is required to maintain correction, and a variety of designs have been employed. One common brace design includes a pair of open-toed high-top straight-last shoes attached to a bar (Fig. 34.8). The brace is set at 60–70° abduction for the clubfoot side and 30–40° abduction on the normal side. The width of the bar is the same as shoulder width. The bar should be bent 5–10° in the center, with the convexity away from the child, to hold the feet in 15° dorsiflexion. A small window cut in the shoe at heel level allows the parents to see and feel that the heel does not rise up. Bracing works only as long as a full correction without residual equinus has been achieved, the brace is comfortable, and the parents develop and maintain a routine for its application.

It is often best to place the child in the brace prior to bedtime, rather than at the same time the child is put to sleep. The brace should be worn day and night for the first 3 months and after that for 12 h at night and 2–4 h in the middle of the day for a total of 14–16 h/day. This protocol continues until the child is 4–5 years of age.

Relapses are seen in approximately 15% of cases. Early relapses are treated by repeating the entire Ponseti casting, tenotomy, and brace sequence. Late relapses, typically after 2 years of age, often relate to muscular imbalance due to over pull of the tibialis anterior. In such cases, the Ponseti method is repeated, and once full abduction is achieved, patients typically require a repeat tenotomy with transfer of the tibialis anterior tendon to the third cuneiform (Fig. 34.9). Long-term bracing is not required following tibialis anterior transfer (see Chap. 35).

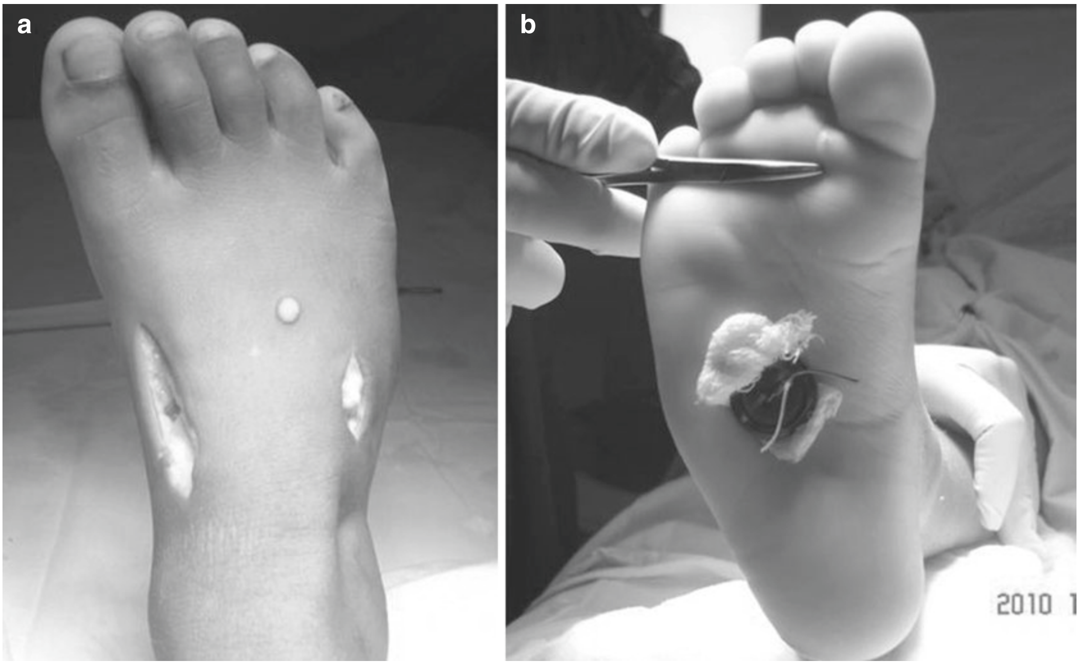

Fig. 34.9 (**a**, **b**) Subcutaneous transfer of the tibialis anterior to the lateral cuneiform

Ponseti in Older Patients

Thousands of children and adults in low- and middle-income countries (LMICs) face the burden of an untreated or "neglected" clubfoot. While the possible physical consequences of an untreated clubfoot include inability to wear shoes, pain, and impaired ambulation, considerable social and cultural consequences add another dimension of disability.

Recognizing that remodeling of chondro-osseous tissues becomes less predictable with age, and is probably minimal after 8 years of age, the Ponseti method has been used in patients beyond walking age in many centers. There are now more than 12 reports concerning application of Ponseti principles in patients older than walking age and up to 10 years of age, suggesting that a plantigrade foot can be achieved without an extensive soft tissue release and/or osteotomy in 66–100% of older patients (Fig. 34.10). Most patients have mild residual equinus, which may require a "modified" squat in patients living in "floor cultures" (Fig. 34.11). The relapse rate can be as high as 25% in these older patients (Fig. 34.12), and additional surgeries are often required. The only long-term study in patients treated after walking age found an initial correction rate of 95%, and while residual deformities were common and mild, patient-reported outcomes were satisfactory at an average follow-up of 11 years (Banskota).

Several adaptations to the Ponseti technique have been used in older patients. Up to 12 casts may be required with each cast lasting 2 instead of 1 week. While 70° abduction is the goal when treating infants, only 20–50° abduction should be expected in older patients. The optimal treatment for equinus has yet to be established, and while percutaneous tenotomy has been successfully performed in patients up to 11 years, an open tendoachilles lengthening with or without posterior release may be required. When adequate dorsiflexion is not achieved after percutaneous release, serial casting may gain further correction. Severe midfoot cavus is difficult to correct with casting and can require plantar fascia release.

Fig. 34.10 (**a**) A 6-year-old with an untreated clubfoot was (**b**–**d**) successfully treated with the Ponseti technique

Fig. 34.11 While (**a**) this patient is able to squat normally following treatment, many have to use a (**b**) "modified" squat to accommodate persistent equinus, even when dorsiflexion is sufficient for normal ambulation

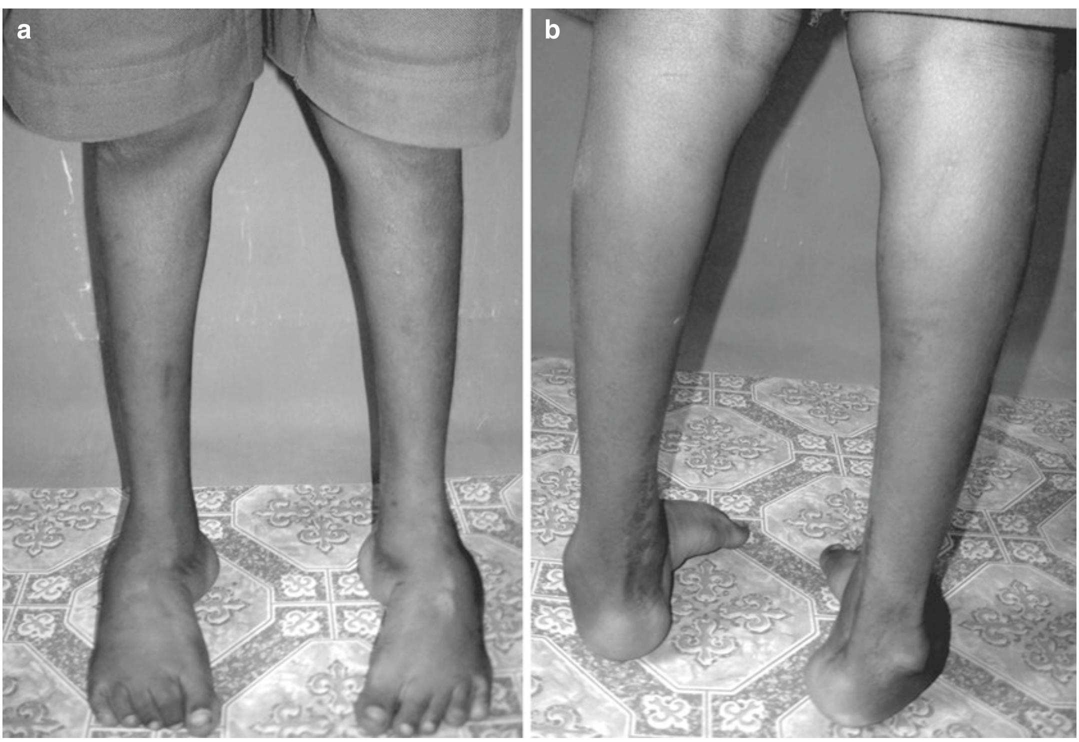

Fig. 34.12 (**a**, **b**) An older patient treated by the Ponseti method, including an open tendoachilles lengthening for severe equinus, had a relapse

While ambulatory patients will rarely adhere to full-time shoe and bar abduction splinting once the last cast is removed, most authors recommend some type of splinting (abduction splint, AFO) to prevent recurrence at least until the child is 4–5 years old, as advised in the original Ponseti method as applied to infants. In patients older than 5 years, nighttime splinting for 1 year can be considered. Further study is required to address these technical concerns.

Recognizing that avoiding extensive intra-articular surgery is the goal, long-term outcomes in these older patients must be assessed relative to alternative treatments, such as soft tissue releases with or without osteotomy, triple arthrodesis, and gradual correction using an external fixator. Even if more extensive surgery will be required, our experience suggests that casting reduces the extent of open surgical procedures, stretches the medial skin reducing the risk of skin breakdown, and allows for calluses and ulcers to heal. This is a work in progress.

Complex Clubfoot

The "complex" or "atypical" clubfoot is distinguished by a short, fat foot with rigid hindfoot equinus, a deep posterior crease, severe cavus with a deep plantar crease, and shortening/hyperextension of the first metatarsal (Fig. 34.13). This variation is seen in feet with a greater severity of disease. It can develop during treatment when the foot slips within the cast. There may also be apex anterolateral bowing of the lower leg. These feet often appear swollen with shiny skin and do not respond to the standard Ponseti technique. If the feet are swollen and inflamed, it is best to give a "cast holiday" for 1–2 weeks till the edema and inflammation subside. A modified Ponseti technique is then applied, wherein the severe cavus is corrected first by dorsiflexing the forefoot with simultaneous pressure over the bases of the first and the fifth metatarsals. Excessive forefoot abduction is avoided and the heel is molded well to avoid slippage in the cast. A short leg cast is first applied and

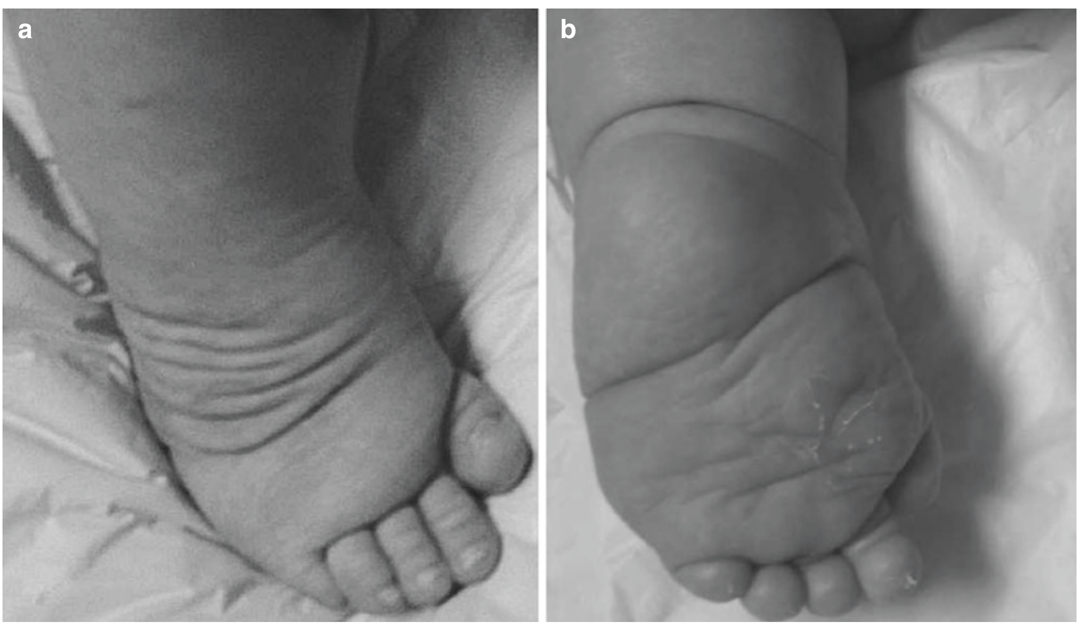

Fig 34.13 (**a**, **b**) A clinical example of a complex clubfoot. Note the short, fat appearance of the foot, as well as the deep posterior and plantar creases, with a short first metatarsal. (Reproduced with permission from Ponseti (Ponseti et al., 2006))

then converted to an above knee cast keeping the knee flexed to 110°. The tenotomy is performed after the cavus is fully corrected, and the final cast has only 40° abduction. The foot is externally rotated 30° in the foot abduction orthosis.

Systems for Service Delivery

There are a number of barriers to implementing the Ponseti method. These involve (1) the patient or family through lack of awareness or fear of treatment, costs, and distance from care; (2) a health system that lacks screening, providers, or supplies; (3) a lack of training for providers and education for families; and (4) a greater financial incentive to do major surgery.

The Ponseti method therefore requires a system for service delivery to overcome these barriers, and important components include screening for early case identification, correction through casting and surgery, and adequate follow-up to maintain adherence with bracing and also address relapses and patient concerns. Screening can be done by educating pediatricians, midwives, community health workers, and others who evaluate newborns. Patients for whom transportation is a barrier may need a rehabilitation hostel or similar housing facility until correction is achieved. Follow-up is challenging in austere environments but is essential as the relapse rate is high if orthotic use is not maintained. One strategy is to utilize community-based rehabilitation workers in the patient's home community. Long-term projects in Uganda, Malawi, Bangladesh, and Brazil have been set up at the national level ("top down"). In Nepal the Ponseti method was started at a single center and has been scaled up through satellites and disseminated to other treatment centers through workshops and training of health providers.

Suggested Reading

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Spiegel DA, Shrestha OP, Sitoula P, et al. Ponseti method for untreated idiopathic clubfeet in Nepalese patients from 1 to 6 years of age. Clin Orthop Relat Res. 2009;467:1164–70.

Additional Resources

Basic Ponseti casting technique. https://www.youtube.com/watch?v=ZWJt_RevEP4.

Global Clubfoot Initiative. http://globalclubfoot.com/ponseti/.

Global HELP. https://global-help.org.

Miracle Feet. https://www.miraclefeet.org/clubfoot/.

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https://www.ponseti.info/publications%2D%2D-resources.html.
Ponseti International Association. http://www.ponseti.info/ponseti-method.html.
Ponseti technique by Dr. Jose Morcuende. https://www.vumedi.com/video/the-ponseti-method-details-tips-and-tricks/.
Ponseti using a model https://www.youtube.com/watch?v=04SsJniyL5w.
Ponseti: arthrogryposis https://www.youtube.com/watch?v=F8s_mlaauss.
Ponseti: complex clubfoot https://www.youtube.com/watch?v=Xn92oHq5Kec.
Ponseti: tenotomy https://www.youtube.com/watch?v=AOx2QEis1_E.
Ponseti: virtual correction. https://www.youtube.com/watch?v=RzHe92JffIs.

35 Algorithm for Neglected Clubfoot and Residual Deformities Following Treatment

J. Norgrove Penny and David A. Spiegel

Introduction

A neglected or untreated clubfoot is a common problem in resource-poor environments (Fig. 35.1). While the pathoanatomy is the same as in patients treated as infants, the treatment becomes more complex with advancing age due to the severity of soft tissue contractures and limited bony remodeling potential. Ponseti management programs have been introduced in more than 100 countries, and surgical treatment for clubfoot is practiced to some extent in most environments, making it reasonable that a surgeon will encounter residual deformities in patients treated previously and must be aware of the specific pathology and the various techniques—alone or in combination—to correct the presenting deformity. The challenges are heightened for patients who do not have access to the treatment facility that allows long-term serial casting, surgical interventions, and follow-up necessary to achieve a plantigrade foot.

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All neglected or untreated clubfeet are not the same; while the hindfoot is always rigid, there are varying degrees of rigidity of the midfoot and forefoot deformities. If the forefoot remains rela-

Fig. 35.1 Father and son with clubfoot. The father never had treatment, while his son had an early posteromedial soft tissue release complicated by relapse of equinovarus

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Fig. 35.2 Some neglected clubfeet point forward or inward during ambulation, suggesting that the midfoot cavus is flexible

tively flexible (no rigid midfoot cavus), the child will bear weight on the lateral border of the foot with the foot pointing either forward or inward (Fig. 35.2). If there is a rigid midfoot cavus deformity, the foot faces backward with all the weight taken on the dorsum. In this latter case, the prognosis for cast correction alone is not as optimistic as when the foot faces forward (Fig. 35.3). Clubfeet which have been treated by Ponseti method, extensive surgical releases, or other surgeries may have one or more residual deformities of variable stiffness. There may also be a dynamic component to the deformity from muscle imbalance, for example, dynamic supination of the foot during swing phase from overactivity of tibialis anterior.

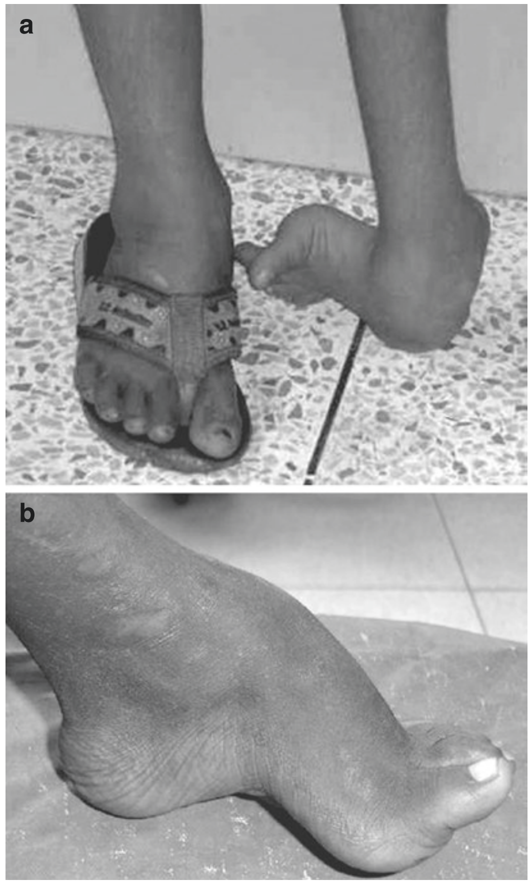


Fig. 35.3 (**a**) In this patient with a rigid midfoot cavus, the foot points backward. (**b**) A lack of dorsiflexion may be due to both hindfoot equinus and midfoot cavus

Treatment Principles

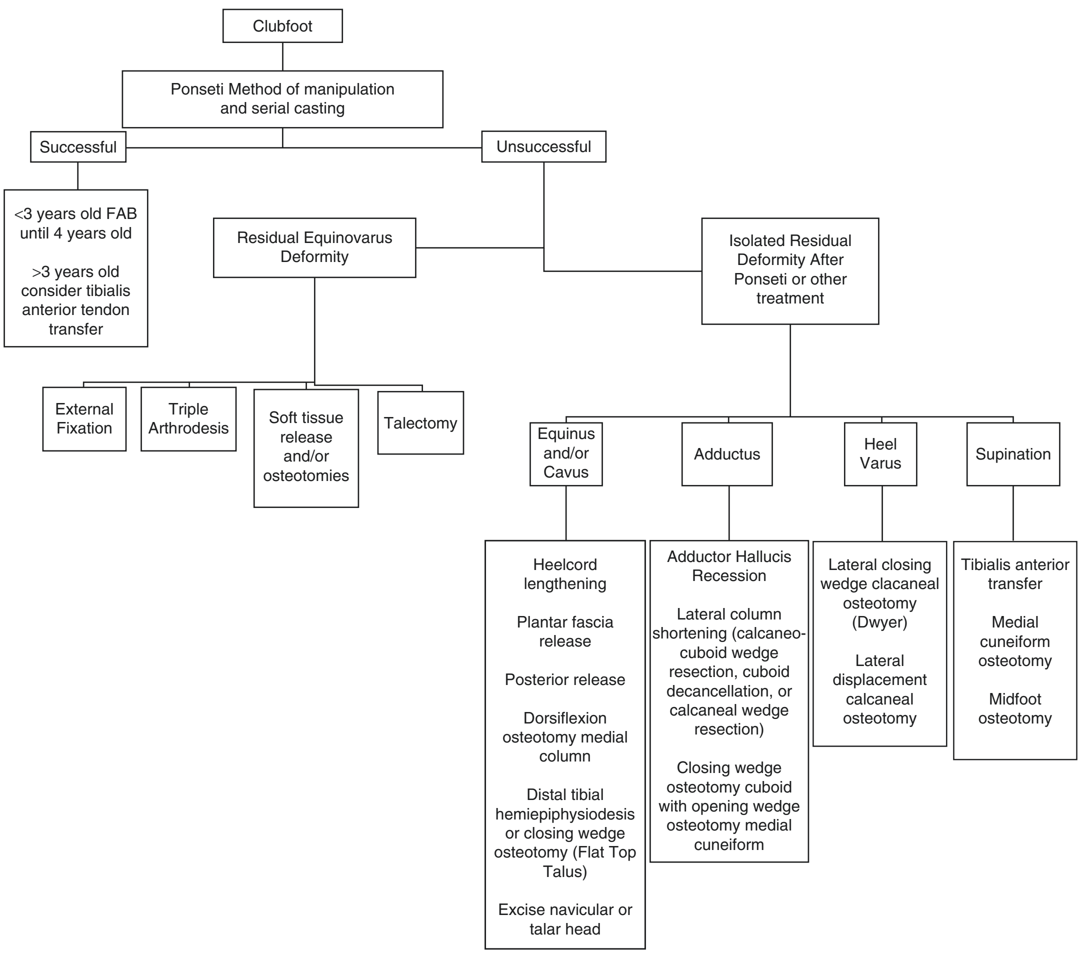
Patients living near an organized treatment facility have access to the full complement of treatment options, which should ideally begin with casting using the principles of the Ponseti method. Where there are committed parents with no barriers to transport and clinic attendance, casting can take place for as long as needed. Where there are committed parents but problematic transport logistics, notably due to poverty and rural living locations, hostel or hospital inpatient care should be made available. When organized rehabilitation services are absent or logistically impossible, primary surgical treatment may be a child's only opportunity for correction.

The Ponseti method, with minor modifications, has shown surprising success in achieving a plantigrade foot in children up to 10 years of age (see Chap. 34). In those cases which fail casting, an "à la carte" approach is used to select the most appropriate surgical procedure based on the residual components of the deformity and their degree of flexibility. Under ideal circumstances, adequate correction can be achieved without intra-articular surgery, reducing the long-term risk of degenerative changes at the ankle and/or midfoot joints. Soft tissue releases (plantar fascia) and extra-articular lengthenings are more desirable than opening joint capsules. In general, children aged 8 and under respond to soft tissue releases and lengthenings with or without a lateral column shortening osteotomy, while those over age 8 with a rigid foot respond best to a combination of soft tissue release/lengthening and osteotomy, a modified Lambrinudi triple arthrodesis, or gradual correction with an external fixator.

Suggested Surgical Algorithm (Table 35.1)

This algorithm is applicable when an organized center is available and will necessarily be modified based on variables related to both the individual and the health system, recognizing that one constellation of treatments will not address every patient's situation. The treatment begins with serial casting using the principles of Ponseti's technique and progresses to surgical procedures as needed to address the specifics. Casting is always beneficial, even in feet previously treated by intra-articular releases or other surgical procedures, by reducing the magnitude of surgery required. Casting in walking-age children is more difficult and time-consuming, and a longer casting period is expected, often over several months. Typically little clinical improvement occurs until after the first three or four casts. In older patients the casts are applied each week

Table 35.1 Algorithm for treatment of clubfeet in lower resource countries



FAB foot abduction brace, *AFO* ankle foot orthosis or two and continue until a plateau in correction occurs.

There should be a low threshold for extra-articular surgery (Achilles tenotomy, tibialis anterior transfer, plantar fascia release, Z-lengthening of tendons) and osteotomies and a high threshold for intra-articular surgery, capsular releases, or arthrodesis. The extensive intra-articular soft tissue releases (posterior, postero-medial, or posterior-medial-lateral) that were common in the past are rarely required with the range of treatment options now available and our understanding of the condition. However, they can be considered in outreach situations in infants or younger children, such as those seen in a "surgical camp" in a remote location where the logistics of serial casting are not possible and there is only one opportunity to obtain a plantigrade foot. In any child over the age of 2–3 years undergoing general anesthesia for surgical correction of clubfoot deformity, a lateral transfer of the tibialis anterior tendon should be considered to prevent recurrence and eliminate the necessity of wearing a foot abduction orthosis.

Preoperative radiographs may be useful when residual deformities are present and surgical treatment is planned and will ideally be obtained in a weight-bearing position. However, with the goal to evaluate alignment in the setting of maximal correction, we favor stress views rather than attempted weight-bearing images. The foot is held in the maximally corrected position for the AP and lateral x-rays. Abnormalities in alignment and findings such as a flat-top talus or dorsal subluxation of the navicular can be identified.

Persistent loss of dorsiflexion may be due to ankle equinus, midfoot cavus, or both (Fig. 35.3b). Equinus is most commonly addressed with a percutaneous tenotomy using local anesthetic with sedation, ketamine, or general anesthesia. If the acceptable dorsiflexion of 10–20° is not achieved, a return to weekly casting after the tenotomy may facilitate full correction. While the upper age range for complete tenotomy has not been determined, tenotomy has been reported in patients up to 10 years of age. Another option in older children is to perform a three-level percutaneous sliding tendoachilles lengthening. A formal Z-lengthening of the Achilles tendon is also an option. A formal posterior release involving the ankle and subtalar joints may help achieve more dorsiflexion acutely, but ultimately these tissue scar and correction may be lost.

Persistent equinus can result from a flat-top talus. Clinically there is a hard end point or bony block to dorsiflexion, while the tendoachilles does not feel especially tight when palpated with the foot in maximum dorsiflexion. The flattening may be observed on a lateral radiograph taken in maximum dorsiflexion. In such cases soft tissue releases will not provide adequate dorsiflexion. In children one option is to perform an anterior distal tibial hemiepiphysiodesis ("guided growth") using a staple or small two-hole plate with one screw in the epiphysis and one in the metaphysis. Correction is slow, but for small deformities, this may suffice. In older patients an osteotomy of the distal tibia will be required, creating a new deformity proximally, to address the intra-articular deformity.

An open release of the plantar fascia may be necessary to correct residual midfoot cavus, while a dorsiflexion osteotomy of the medial cuneiform or proximal first metatarsal (if the physis has closed) can be considered when more correction is needed. In severe cases the navicular impinges on the head of the talus when attempting to dorsiflex the foot. Excision of the navicular can be considered although this is rarely required.

Midfoot cavus may also be due to dorsal subluxation of the navicular, often presenting with a triangular appearance, in feet previously treated by extensive soft tissue releases. Options for surgical management include soft tissue release followed by repositioning the navicular and pinning, versus isolated talonavicular fusion after realignment. Remember that fusing the talonavicular joint severely limits subtalar motion and is essentially the same as a triple arthrodesis. In contrast, an isolated calcaneocuboid fusion limits subtalar motion by only about 20%.

Persistent adduction deformity involves a short medial column with relative lengthening of the lateral column and may be treated by release of the abductor hallucis if mild, but more commonly a lateral column shortening is required. Options include excision of the anterior process of the calcaneus (Lichtblau procedure) or the Evans calcaneocuboid wedge resection arthrodesis. The primary author prefers the Lichtblau procedure in children less than 6 years, hoping for a mobile pseudoarthrosis to preserve some joint motion. In children older than 6 years, a calcaneocuboid arthrodesis is preferred, providing adequate correction with less potential for relapse. Cuboid decancellation is not recommended since correction is achieved distal to the deformity and does not correct the obliquity at the calcaneocuboid joint (Fig. 35.4). Another option is a closing wedge osteotomy of the cuboid with placement of the resected bone into an opening wedge osteotomy of the medial cuneiform.

Where there is persistent hindfoot varus, a lateral closing wedge osteotomy of the calcaneus (Dwyer) or a lateral calcaneal displacement osteotomy (calcaneal slide) can be performed. An oblique cut is made in between the posterior facet and the calcaneal tuberosity with the plantar edge of the cut close to the posterior facet and the dorsal edge closer to the tuberosity. In the calcaneal slide, the tuberosity is displaced laterally by 50% of its width and then fixed with Steinmann pins or screws.

Persistent forefoot supination is difficult to treat. In this case, the medial column of the forefoot is elevated relative to the lateral column (forefoot is in varus), and the goal of treatment is to have a neutral hindfoot with both the first metatarsal and fifth metatarsal on the ground, so the medial column needs to be brought down into plantarflexion. Milder cases in which there is no fixed contracture would benefit from anterior tibialis tendon transfer laterally. If there is fixed dorsiflexion of the medial column, a plantar flexion osteotomy of the medial cuneiform or the proximal first metatarsal (if physis has closed) can be considered to correct the forefoot varus. More severe cases require a midfoot or transcuneiform osteotomy, but this procedure—when combined with rear foot osteotomies—results in a very rigid foot. It might be more appropriate to consider a triple arthrodesis in these circumstances.

While some older children or adolescents with a rigid clubfoot will respond to a more limited surgical approach (Fig. 35.5), when an extended treatment course is impossible, triple arthrodesis is the most expeditious way to gain correction with the fewest number of complications. Growth of the foot is not affected any more than with osteotomy procedures. The first author prefers a modified Lambrinudi triple arthrodesis and has performed this procedure to good effect in low-resource conditions (Fig. 35.6).

A standard Ollier lateral incision is made over the anterior calcaneus. Medial dissection or medial soft tissue release is not necessary, with concern that both medial and lateral dissection

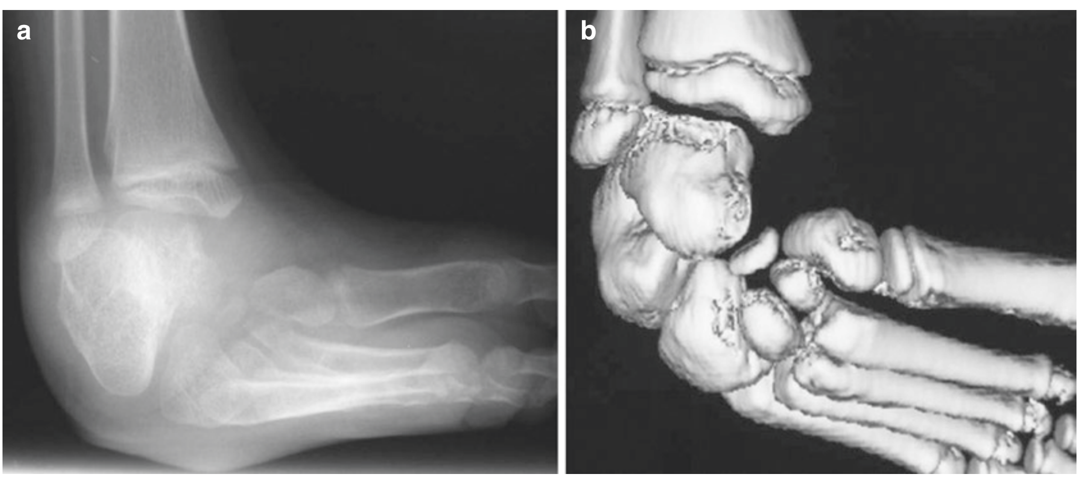


Fig. 35.4 (**a**, **b**) Neglected clubfeet always show considerable obliquity of the calcaneocuboid joint

Fig. 35.5 (**a**–**e**) This teenage girl presented with bilateral clubfeet. The right foot had been previously treated (**a**, **b**). On physical exam her foot could be brought to the midline in the coronal plane (**c**), and the hindfoot was rigid lacking 30° of dorsiflexion, accompanied with significant midfoot cavus. Clinically the prone hindfoot flexibility test showed that the hindfoot varus could be corrected to neutral. Based on the desire to avoid a triple arthrodesis and to correct the deformity under a single anesthetic, we elected to perform a plantar fascia release; an open Z-lengthening of the Achilles tendon, the tibialis posterior, and the flexor digitorum longus with an intramuscular recession of the flexor hallucis longus; as well as a dorsiflexion osteotomy of the medial column, a lateral column shortening by calcaneocuboid arthrodesis, and a tibialis anterior tendon transfer (**e**)

Fig. 35.5 (continued)

risks devascularizing the talus. Obliquity of the calcaneocuboid joint is usually pronounced and influences the orientation of the first osteotomy—a transverse cut in the anterior process of the calcaneus perpendicular to the lateral border of the hindfoot. A more conservative transverse osteotomy of the cuboid is made perpendicular to the lateral border of the forefoot. The head and neck of the talus are excised obliquely beginning at the junction of the talar neck and the articular surface of the head of the talus, and an aggressive anterior wedge resection is taken at an oblique angle from the anterior process of the calcaneus. This creates a dorsal-lateral-based closing wedge osteotomy. The navicular is decorticated, and the posterior facet of the subtalar joint is excised.

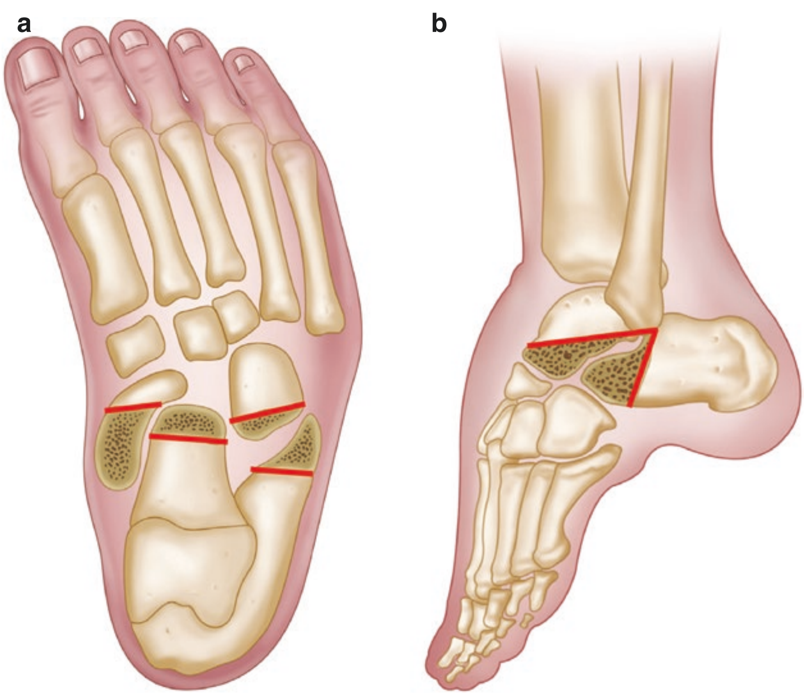


Fig. 35.6 (**a**, **b**) The first step in a Lambrinudi triple arthrodesis is a lateral column shortening and calcaneocuboid fusion, removing more bone from the calcaneus than the cuboid. The orientation of the calcaneal cut is perpendicular to the long axis of the lower leg, and a triangular wedge is removed owing to the obliquity at the calcaneocuboid joint. The second cut removes the head and neck of the talus as well as the anterior portion of the calcaneus in the sagittal plane. The talonavicular resection is completed, followed by the removal of the posterior facet of the subtalar joint

Correction is achieved by dorsal and lateral displacement of the forefoot on the hindfoot.

While fixation with staples, K-wires, or screws is desirable, careful cast correction without fixation can give an acceptable result (Fig. 35.7). Personal experience has shown that extensive soft tissue releases and osteotomies, when compared to triple arthrodesis, are associated with more complications, such as wound healing and infection, and a longer operative time and result in equivalent

Fig. 35.7 This patient had an open tendoachilles lengthening and a triple arthrodesis for a rigid left clubfoot. (**a**) Preoperative appearance, and (**b**) postoperative lateral radiograph demonstrates fixation with K-wires fashioned into staples. (**c**, **d**) Clinical appearance following the procedure

Fig. 35.8 Gradual correction with a ring fixator

stiffness. Surgeons from the polio era considered triple arthrodesis a very adaptable and versatile procedure, and variations can correct a range of complex foot deformities. While talectomy is an option for rigid clubfeet, especially those associated with arthrogryposis and myelodysplasia, the long-term results have been suboptimal.

An alternative surgical approach is gradual correction by differential distraction using an external fixator (Ilizarov, Joshi, Taylor Spatial Frame, or similar devices) (Fig. 35.8). This requires knowledge and experience with the technology by the surgical team, committed parents and patient, and an inpatient rehabilitation hostel or hospital admission in most circumstances. Complications such as infection are a significant risk if patients are allowed to return to their home village with the fixators in place. Advantages include less open dissection and retention of foot length. The disadvantages are the long treatment course and a significant rate of stiffness and relapse. The correction can be achieved either with or without concomitant osteotomies of the midfoot or hindfoot.

Recently several authors have adopted Ponseti's principles using a ring fixator. Tripathy et al. have advocated a staged approach. In the first stage, a percutaneous release of the plantar fascia is combined with placement of the ring fixator, with two wires through the talar head to fix its position in space. The foot is abducted around the head of the talus as in the Ponseti casting technique. When sufficient abduction is achieved, the midfoot frame is removed and a hindfoot frame applied for the gradual correction of equinus (Tripathy).

In a stiff neglected unilateral clubfoot, a fixator can gain length and soft tissue stretching before proceeding to triple arthrodesis or midfoot osteotomy. This has been the experience of surgeons in India where the Joshi fixator has been used extensively. In severe, bilateral neglected clubfeet, asymmetric foot length is not an issue, and triple arthrodesis or osteotomies become more practical. Our experience suggests there is no significant difference in stiffness comparing patients treated by triple arthrodesis with patients treated by distraction external fixation and soft tissue release with osteotomies.

Correction Maintenance

In the Ponseti method in newborns, long-term bracing with a foot abduction orthosis is required as outlined in the previous chapter. Bracing is a logistic challenge in many environments, and lack of adherence to the bracing program is the most frequent cause of relapse after correction is obtained, at least in children under 2 years of age. Full-time bracing is impossible in children of walking age. The author's practice includes abduction bracing at night and nap time only until the child is 3 or 4 years of age.

In children over age 3 at the time of correction and when operative facilities are available, the first author considers a tibialis anterior tendon transfer at the time of heel cord tenotomy, bypassing the need for foot abduction bracing. Postoperatively, 6 weeks of casting is followed with an ankle foot orthosis (AFO) until outgrown. The AFO is used at night and part-time during the day allowing a few hours out of brace to facilitate mobility and strengthening. Bracing is not required after triple arthrodesis.

Suggested Reading

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36 Limb Deficiencies

Anna D. Vergun and Hugh G. Watts

Overview

Limb deficiencies can result in functional disability and are often associated with significant social stigmas. Surgeons treating these conditions in resource-rich countries work in a team that includes prosthetists, physical and occupational therapists, and social workers. In places with limited resources, failure to appreciate the limitations imposed by the absence of such professionals, or deficiencies in their skills, can result in a lack of functional improvement and unnecessary use of resources. Treatment must be individualized and tailored to personal or cultural beliefs. The purpose of this chapter is to equip the surgeon with some basic principles to guide management of limb-deficient children in a variety of circumstances.

Most limb-deficient children have normal intellects and developmental milestones. Deficiencies may change the way a child crawls or walks, but will not change their major motor milestones. Interventions depend on functional and social circumstances.

Acquired amputations will have normal bone, bone growth potential, and soft tissues proximal to the amputation. Non-acquired amputations (congenital constriction bands), congenital limb deficiencies, and dysplasias commonly require an amputation and prosthetic fitting or limb reconstruction and surgery to address the accompanying foot deformity; hip, knee, or ankle instability; and limb length discrepancy (see Table 36.1, Fig. 36.1). In these cases, it is important to look for and recognize subtle deficiencies of the whole limb. Cardiac and renal anomalies are associated with congenital spine and limb deformities. The surgeon may be the first person to recognize that other organ systems are affected and should refer the patient appropriately.

It is important to address the family's fears of the recurrence of similar deformities or deficiencies in future offspring. However, if there is not already a family history, it is extremely unlikely future children will be affected as most cases are thought to be spontaneous mutations.

Both acquired and congenital amputations from constriction bands can have long bone overgrowth, requiring surgical capping of the bone ends with cartilage (Fig. 36.2).

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Table 36.1 Congenital limb deficiencies. Limb deficiencies may involve the femur, tibia, or fibula and are associated with a spectrum of abnormalities within the osseous and soft tissue structures

Congenital limb deficiencies	Features	Treatment options
Femoral deficiencies	*Congenital short femur* (femoral length >50% of normal side)	If congenital short femur, then lengthen femur (or shorten contralateral femur)
	Proximal femoral focal deficiency (*PFFD*)	If PFFD with stable hip, length <50%, then proximal femoral osteotomy, foot ablation, and knee fusion with fitting as a through-knee amputee
	Stable hip (coxa vara, has proximal femur and acetabulum ± pseudarthrosis	
	Unstable hip or subtotal absence of proximal femur	If PFFD with unstable or subtotal absence, then foot ablation and knee fusion or custom prosthesis
Longitudinal deficiency of the fibula	Femoral deficiency common	If three or more rays on foot, then foot reconstruction, epiphysiodesis versus lengthening for leg length inequality
	Fibula absent or hypoplastic	
	Knee cruciate deficiency, patellar dysplasia	If severe leg length discrepancy anticipated and/or severe foot deformity (<2 rays), then foot ablation and prosthetic fitting as a below-knee amputee
	Tibia short with anteromedial bow	
	Equinovalgus foot with tarsal coalition, lateral deficiency	
Longitudinal deficiency of the tibia	1/1 million births	If no tibia present and no knee extension, then through-knee amputation and prosthetic fitting as through-knee amputee
	Most sporadic, rarely genetic (AD, AR)	
	Hand anomalies most common, visceral rare	If proximal tibia present, then foot ablation ± proximal tibiofibular synostosis and prosthetic fitting as a below-knee amputee
	Femoral hypoplasia	
	Tibia can be (1) completely absent, (2) proximal tibia present with intact extensor mechanism, or (3) distal tibial deficiency with diastasis between tibia and fibula	If distal diastasis, then foot ablation and prosthetic fitting as a below-knee amputee
	Knee cruciate deficiency, patellar dysplasia	
	Fibula angulated, dislocated proximal tibiofibular joint	
	Equinovarus or equinus foot	

Patient Evaluation

The history focuses on limb function by considering the following questions:

- What are the missing segments, and how do they affect function?
- Are there any muscle, nerve, fat, or skin abnormalities or dimples to suggest additional soft tissue involvement?
- What is the resting posture of the limb?
- What muscle groups are used to effectively flex, extend, abduct, and adduct the limb?
- Which joints are stable or unstable?

Thoroughly examine both upper and lower extremities, look at the spine, and watch the child move around and do activities of daily living. Focusing the exam on the most severely involved limb is a common pitfall. Carefully consider what tasks are functionally important for the child and how surgery may improve or worsen their function. For instance, a child with PFFD may have a very externally rotated femur with limited hip range of motion. Internally rotating the femur may improve the gait but will not easily allow for sitting cross-legged on a floor, which is important in some communities. If there is an associated scoliosis, determine how important spine flexibility is for gait and other activities.

For the lower limbs, determine the length inequality. The relative contribution of the femoral segment is determined with the hips and knees flexed while the child lies supine on a firm surface. The relative contribution from the leg

Fig. 36.1 A spectrum of abnormalities occurs in patients with longitudinal deficiencies of the femur, tibia, and fibula. Variations of femoral deficiency include (**a**) congenital short femur and (**b–d**) proximal focal femoral deficiency. Tibial deficiencies include (**e**, **f**) complete absence of the tibia, (**g**, **h**) presence of an intact proximal tibia and extensor mechanism, (**i**) tibiofibular diastasis, (**j**) a fibular deficiency with a dysplastic fibula, and (**k**) post-surgical fibular to proximal tibial transfer with fusion of the calcaneus to the distal fibula (modified Boyd) to improve function as a below-knee amputee.

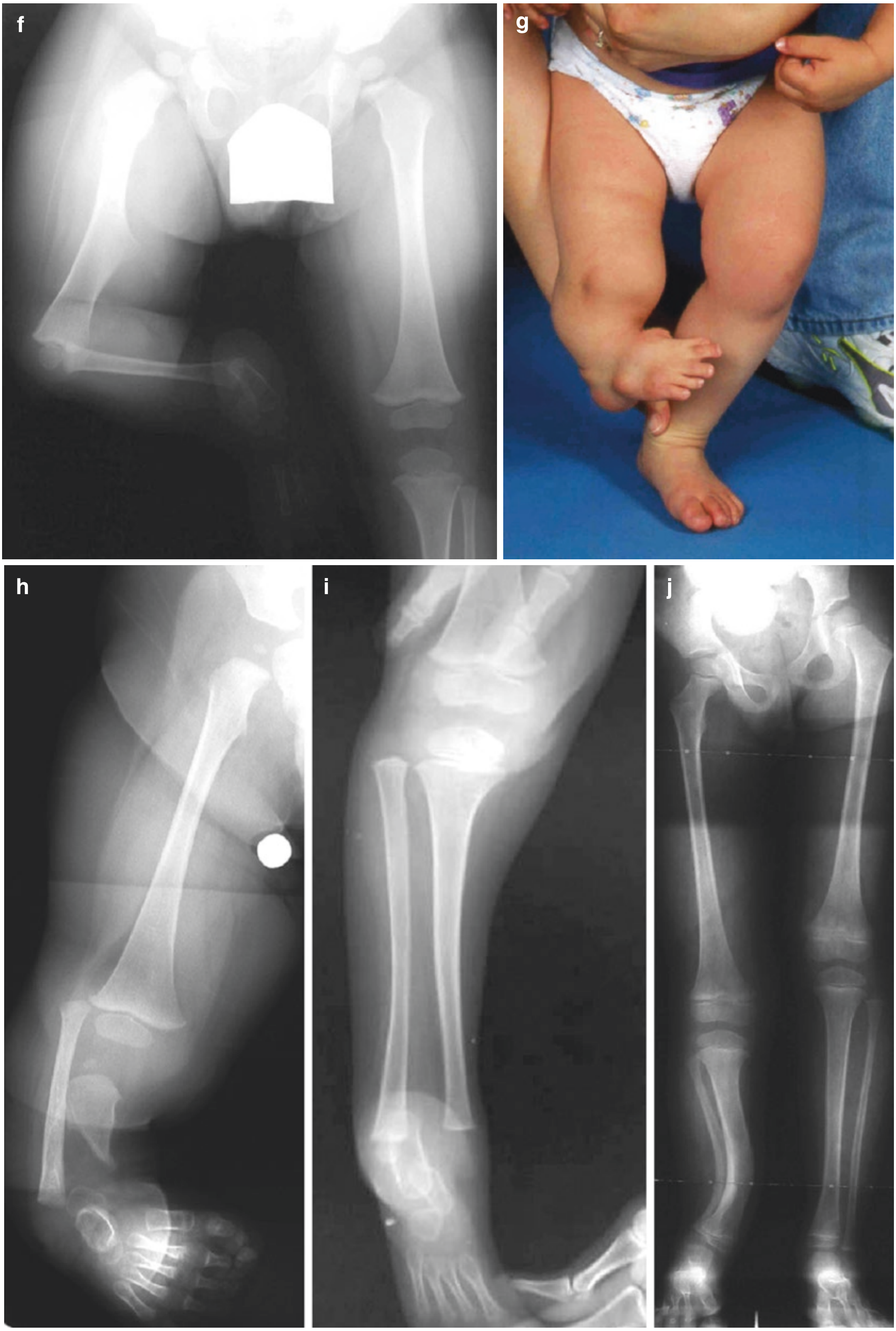

Fig. 36.1 (continued)

Fig. 36.1 (continued)

and foot segments is determined with the child prone with the hips extended and the knees flexed. For children who can stand, the total discrepancy can be measured with the patient standing on calibrated wooden blocks or a measurable platform. Contractures at the hip, knee, and/or ankle may contribute to the functional discrepancy, as may shortening associated with a foot deformity, such as clubfoot.

Additional Studies

X-rays supplement clinical information regarding the location of a bone deformity and the limb length discrepancy. If there is a joint contracture or the child is very young, lateral views of both lower limbs give a good idea of any relative discrepancy. Delayed ossification of the cartilage anlage can give the appearance of a missing joint. Look for secondary signs of joint formation by examining the more normal side of the joint. For instance, a well-defined acetabulum indicates the presence of a cartilaginous femoral head. An ultrasound can help identify an unossified or partially ossified cartilaginous anlagen. If the local anatomy remains unclear, it may be wise to wait and reevaluate in 1 or 2 years.

General Treatment Considerations

Predicting future growth is essential, and the surgeon should be prepared to predict the projected discrepancy.

For an infant or small child with a congenital, (non-acquired) deficiency, the limbs will grow proportionally. An estimate of the projected discrepancy will determine if an amputation at a young age should be considered. A useful tip: when comparing limb lengths, a heel on the shorter side that rests at the level of the mid-tibia on the longer side will also rest at this level at skeletal maturity. In an average height person, the distance from the mid-tibia to the ground is about 20 cm, which is about the maximum difference one would consider lengthening a limb in a resource-rich country. This can help project length differences and guide whether an amputation or length equalizing surgery is most appropriate.

At maturity, the average length of a femur is 41 cm for girls and 44 cm for boys [1, 2]. The

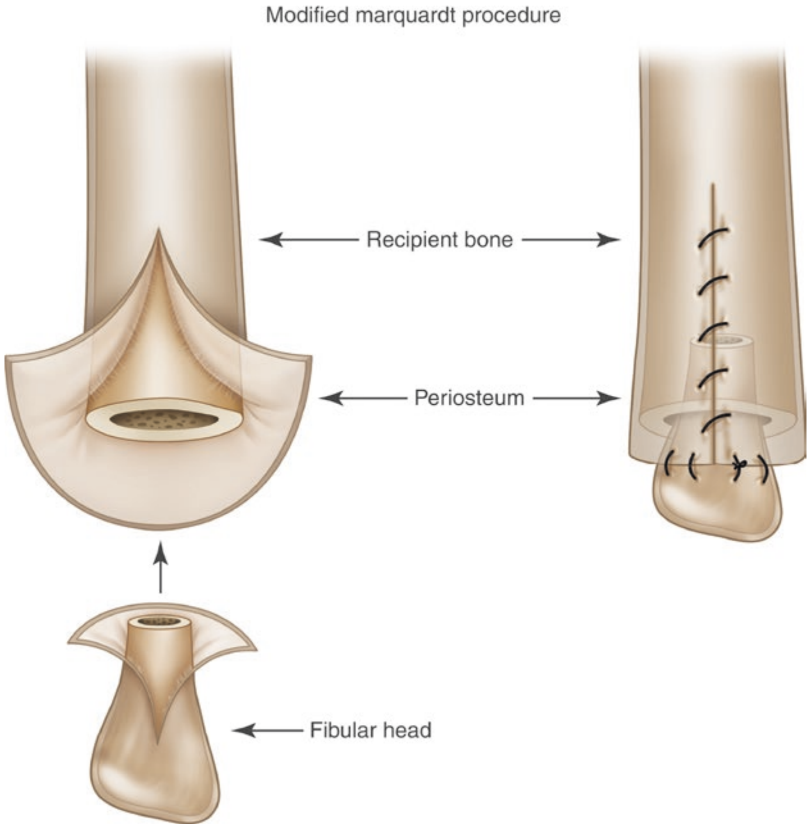

Fig. 36.2 Modified Marquardt procedure. The periosteum is reflected off the distal aspect of the recipient bone, as well as off the proximal end of the "cap" (fibular head). The proximal aspect of the fibular graft is placed into the recipient bone, and the periosteal sleeve from the fibular graft is repaired. The periosteal sleeve from the recipient bone is wrapped around the graft and sutured to itself and to the periosteum over the distal aspect of the fibular graft

average length of a tibia is 34 cm for girls and 37 cm for boys [1, 2]. For example, if the affected femur measures 80% of the length of the normal, contralateral femur, a rough estimate of the discrepancy at maturity will be 20% of 44, or 8.8 cm, for a boy.

Another rough guide: girls reach half their skeletal height by age 3 and boys by age 4. The discrepancy at these ages can be doubled for an estimate of final discrepancy. At ages 6 for girls and 8 for boys, the discrepancy can be multiplied by 1.5 [3].

For children aged 8 and older with a congenital deficiency, while there is still future growth to consider, a large projected discrepancy at maturity will be obvious on clinical exam, and management decisions can be made without detailed calculations. For projected discrepancies ≤10 cm, a more accurate assessment is important to consider timing of an epiphysiodesis or an acute shortening to better equalize the limb lengths. To project the final discrepancy and time for epiphysiodesis, the arithmetic method is simple and reasonably accurate [4, 5] (Table 36.2).

In the setting of growth arrest from trauma or infection, assume normal growth parameters per year until skeletal maturity. Add this value to the

Table 36.2 Arithmetic method [3, 4]

This method is used in timing epiphysiodesis in patients older than 8 years, based on several assumptions
1. Distal femoral growth plate grows at 3/8 in. (9 mm) per year
2. Proximal tibial growth plate grows at 1/4 in. (6 mm) per year
3. Boys stop growing at 16 years of age
4. Girls stop growing at 14 years of age
5. If one of the growth plates is completely arrested, the discrepancy will increase at a rate corresponding to the normal rate of growth for that plate. Otherwise, it will increase at 1/8 in. (3 mm) per year
6. Calendar age is adequate in assessing growth, and skeletal age need not be assessed

current discrepancy to project the final discrepancy. For children affected at a very young age—for example, neonatal sepsis with total physeal ablation—it is useful to know the percentages of growth provided by each growth plate for the entire limb. These are roughly as follows: proximal femur, 15%; distal femur, 35%; proximal tibia, 30%; and distal tibia, 20%. The yearly growth of individual physes has also been estimated (see Chap. 26, Table 26.2).

Determining the skeletal age of the child is the source of the greatest error in predicting limb length discrepancies. The calendar age is clearly the most convenient number to use; however, children undergo a prepubertal growth spurt at a variety of ages, and growth can be severely affected by malnutrition.

Predicting future function is critical when planning treatment. One of the first considerations is the child's access to skilled prosthetic care. Anything other than a standard below- or above-knee prosthesis requires more skill to make, and a poorly fitting prosthesis will be painful and lead to pressure sores, infection, and nonuse. If the patient with a short lower limb can be fitted for a standard prosthesis without changing the limb (e.g., a small foot can be incorporated into the prosthesis), this may be a good first step for management. Though this avoids surgery and maintains a good weight-bearing end to the limb without the prosthesis, reliable access to a good prosthetist is the final determinant to success. If unsure of the skill of the prosthetist, ask what surgical modifications can be made to the limb to simplify the prosthesis and provide a better fit.

For acquired amputations, either from trauma or infection, effort should be made to preserve growth of the physis in young children. For instance, the bone and physis may be unaffected, but there may be inadequate distal soft tissue coverage for primary closure. Instead of amputating at a higher level, which would sacrifice the growth plate, the long bone can be shortened at the metaphyseal diaphyseal junction, allowing the soft tissues to telescope for primary skin closure over the growth plate.

Avoid mid-diaphyseal amputations in children if at all possible because of bone overgrowth. If this cannot be avoided, the surgeon should cap the distal bone with an osteochondral graft, as described by Marquardt [6]. This can be taken from the amputated limb, such as a metatarsal head, or from the proximal fibula with good success for permanently halting the painful overgrowth [7]. The periosteum from both the donor and recipient bone should be approximated with suture after the bone is wedged into the canal with an interference fit. Cartilage capping is ideally performed at the time of amputation but can be equally successful with a fibular head autograft to treat overgrowth that has already occurred (Fig. 36.2).

Avoid scars along the weight-bearing portion of the limb. Begin shrinking the stump as early as 2 weeks postoperatively to prepare for prosthetic fitting. Unlike adults, the skin, including split-thickness skin grafts, and other soft tissues will often hypertrophy at the weight-bearing end of the stump.

Upper Extremity Deficiencies

The goal for the upper extremity is to assist activities of daily living. Do not take off nubbins unless they are problematic, as they provide traction and sensation. Patients with unilateral upper extremity deficiencies often compensate with the contralateral upper extremity, while those with bilateral deficiencies may be able to compensate with their lower extremities. When the deficiency is well compensated, it is inadvisable to recommend an upper extremity prosthesis that is insensate. Many children will reject upper extremity prostheses unless introduced before 1 year of age. In the rare circumstance when a child is poorly compensated, such as bilateral below-elbow deficiencies, a Krukenberg reconstruction can be considered [8], as described in Chap. 41. In addition, while a severe foot deficiency may make ambulation difficult, the foot may be used to substitute for the hands if the child is missing both upper extremities (Fig. 36.3). In this case, it would be shortsighted to amputate the feet.

Fig. 36.3 This child with the absence of both upper extremities will learn to use his feet for a variety of tasks

Lower Extremity Deficiencies

The most appropriate management depends on the severity of the foot deformity, knee and ankle joint stability, ongoing access to a prosthetist, and the social situation of the child. While longitudinal growth will usually remain proportional, angular deformities and contractures can increase, and the gait will change as the child matures. A deformed but functional joint in a child may become painful and nonfunctional in an adult.

See Table 36.1 for major categories of congenital lower extremity deficiencies and common treatment algorithms. If possible, preserve the knee joint, as energy expenditures are considerably less for a below-knee amputation versus one more proximal. However, an above-knee amputation is preferable in the absence of active knee extension. If the femur is >50% the length of the contralateral side, consider a through-knee amputation. For the patient with an extremely short femur, <50% of the length of the contralateral femur, consider combining a knee fusion with a foot ablation procedure, so the patient can be fitted as a through-knee amputee. The authors prefer a Boyd amputation (excision of the ankle joint, including the distal tibial physis, with fusion of the calcaneus to the distal tibia) rather than a Syme amputation (ankle disarticulation) (see Chap. 43).

Any of these procedures may need to be combined with an epiphysiodesis to allow the mechanical knee to fall near the same level as the contralateral side at skeletal maturity. Large discrepancies in knee height lead to differences in swing phase duration and can produce a dysfunctional compensatory gait pattern. The surgeon should plan for the femur to be shortened with a timed epiphysiodesis so the above-knee amputation results in a stump that is about 5–6 cm proximal to the contralateral knee at skeletal maturity. A below-knee prosthesis requires about 10 cm for cosmetic appearing ankle and foot components, and the ideal stump length is between 15 and 25 cm at skeletal maturity.

The timing of surgical interventions depends on the projected limb length discrepancy and whether it is more reasonable to preserve the affected limb and shorten the long side or if an amputation on the affected side is better. Ideally, intervention is timed to allow the child to reach his normal motor milestones. Amputations are psychologically easier for the child the earlier they are performed. If the function of the limb is uncertain, particularly concerning hip and knee extension, it is best to wait until the child develops and the clinical picture clarifies. In the meanwhile, children can be fitted with an extension orthosis or a large external shoe lift to improve their gait (Fig. 36.4).

In most austere environments, lengthening the short limb is not an option due to the high complication rate and need for ongoing monitoring and surgical interventions.

Although the concept has been popularized that a limb should not be shortened more than 5 cm, this has no basis other than concern for the appearance of a relatively long trunk relative to the limbs. If shortening a long limb by 10 cm with an epiphysiodesis will be a simple surgery to address a complicated problem, it is probably

Fig. 36.4 An extension orthosis on an adolescent girl with a congenitally short femur

the right choice despite cosmetic concerns. A common error is to correct the current discrepancy and not the projected discrepancy at maturity. An acute shortening can be performed at any time; however, the surgeon is limited up to 5 cm in the femur and 3 cm in the tibia due to difficulty with soft tissue closure after the soft tissues telescope around the shortened segment. Acute shortenings can be staged once the soft tissues have shrunk to provide a larger magnitude of shortening.

Prosthetic Pearls

- Even prosthetists who have considerable experience with adult amputees may not understand all the needs specific to children. Ideally, the surgeon and prosthetist work together to best address the individual needs of the child.
- Due to growth a child may need a new socket every 6 months or a year. A prosthetic foot will last about 1 year, and a prosthetic knee can last between 1 and 3 years before needing replacement.
- Pain in the residual limb may be a result of poor socket fit, a bony prominence like tip overgrowth or exostosis, a neuroma, or skin problems from pressure or sheering of the skin against the inside of the prosthetic socket. Sometimes the socket needs to be changed, and sometimes the surgeon needs to change the shape of the limb. This is best determined by a conversation between the surgeon and prosthetist.
- Bilateral amputees may not initially tolerate prostheses at full height, especially if their walking has been delayed due to limb deformities. Their initial prostheses should allow for a low center of gravity with height gradually increasing as tolerated.

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Internet Resources for Limb Deficiency and Loss

For amputees: https://www.amputee-coalition.org/.

For care providers: http://www.acpoc.org/.

The Association of Children's Prosthetic-Orthotic Clinics provides a comprehensive resource of treatment options.

This site provides education, support and advocacy.

37 Evaluation and Treatment of Angular Deformities

Sanjeev Sabharwal, Richard M. Schwend, and David A. Spiegel

Introduction

The infant's lower limbs are aligned in varus from birth until approximately 18–24 months of age, after which they are in valgus. Valgus peaks between 3 and 4 years, and adult alignment (5–7° valgus) is achieved at approximately 7–8 years. When faced with a deformity, the surgeon must identify those that are pathologic and affect function or cosmesis, cause pain, or will have consequences later in life. Coronal plane deformities can be due to one or more of the following causes: angulation of the femur and/or tibia, intra-articular bony deficiencies at the knee, and ligamentous hyperlaxity. Physical examination along with full-length standing radiographs and other pertinent imaging modalities are used to individualize treatment (Fig. 37.1).

Limb bowing can be generalized or focal. The differential diagnosis of the cause of genu varum or genu valgum includes physiologic, posttraumatic (malunion, sequelae of physeal fractures), postinfectious, inflammatory (juvenile arthritis), and systemic diseases (rickets), generalized bone disorders (skeletal dysplasias, osteogenesis imperfect, enchondromatosis, osteochondromatosis, neurofibromatosis), and congenital causes such as limb deficiencies. Tibial deformity can be anterolateral (apex anterior and lateral – associated with congenital pseudarthrosis), anteromedial (apex anterior and medial – associated with fibular hemimelia), and posteromedial (apex posterior and medial – associated with a calcaneovalgus foot deformity).

Recognizing that many deformities are multiplanar and that planning complex limb realignment is beyond the scope of this book, the authors' goal is to provide a basic understanding of (1) lower limb malalignment, (2) how to identify components of the deformity, and (3) surgical options for achieving correction.

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Fig. 37.1 Examples of (**a**) genu varum and (**b**) "windswept" limb deformities

Clinical Evaluation of Limb Deformities

The history should identify previous traumatic injuries or infections and/or medical or nutritional issues, suggesting an underlying metabolic problem. A family history can identify similar limb malalignment in other family members and familial bone diseases. Ask how the patient and family perceive the "problem": is it purely cosmetic, or is there pain or limitation in activities?

The physical assessment begins with general health and nutrition. Height and weight should be measured and compared with normative data. The lower extremity exam includes observational gait analysis and focuses on limb alignment and leg lengths, both assessed while standing with the patellae facing forward. Hip, knee, and ankle range of motion are measured, as contractures can be sources of apparent limb length discrepancy. Knee joint stability is tested, as ligamentous laxity can contribute to a varus or valgus moment with weight-bearing, often associated with a "thrust" during ambulation. The spine should be examined to rule out associated spinal deformity or pelvic obliquity, which can contribute to apparent limb shortening and gait deviations.

Radiographs are essential when evaluating a limb deformity, ideally as standing full-length AP (patella pointing forward) and lateral radiographs of both lower extremities. If long cassettes are unavailable, consider separate standing AP and lateral films of both the femur and the tibia/fibula, including the proximal and distal joints in each film. When weight-bearing views are unavailable, knee laxity must be inferred from the clinical exam. Look for physeal widening and other abnormalities seen in rickets or certain skeletal dysplasias. Upper extremity and spine x-rays may be necessary to confirm underlying diagnoses and optimize the patient preoperatively.

Preoperative Planning

In general, the *mechanical axis of the leg* passes from the center of the femoral head through the medial tibial spine and the center of the ankle joint (Fig. 37.2). The *anatomic axes of the femur and tibia* are drawn parallel to the shaft of each bone. The *mechanical axis of the femur* is a line from the center of the femoral head to the center of the knee. The mechanical and anatomic axes of the tibia are identical. Tibiofemoral angles can either be anatomic – an angle formed by the intersection of the anatomic axes – or mechanical, an angle formed by the intersection of the mechanical axes. When using the anatomic axes, the value is normally 5–7° valgus. In the sagittal plane, the mechanical axis runs from the center of femoral head to the center of the ankle, passing

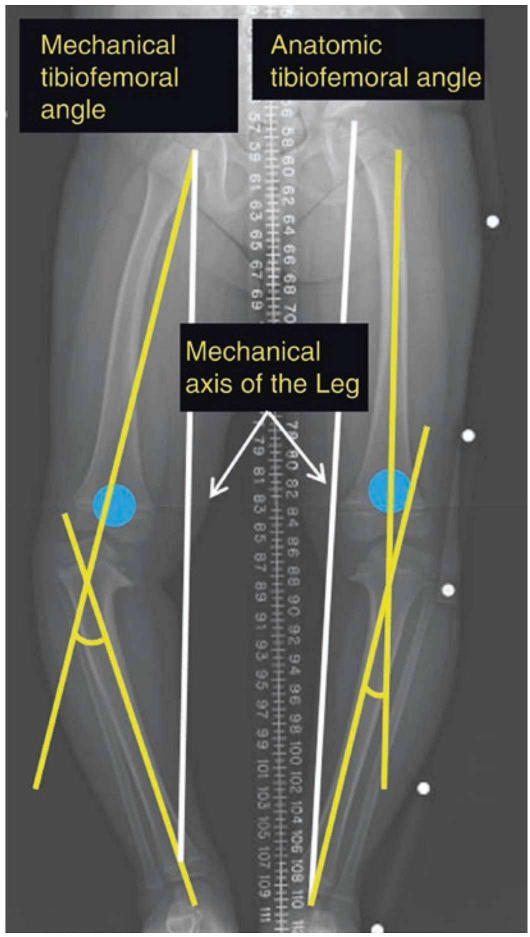

Fig. 37.2 A patient with Blount's disease is shown illustrating the mechanical axis and both the mechanical and anatomic tibiofemoral axes. Note that the left patella faces forward, while the right is medial and the limb is slightly rotated. The blue circles indicate the location of the patellae

anterior to the knee joint. This facilitates locking the knee in extension during stance and minimizes the work of the knee extensors.

Preoperative planning should:

- Identify the mechanical axis deviation (in mm from the center of the knee joint)
- Determine the source of malalignment – femur, tibia, joint laxity, or any combination
- Define the planes and levels of deformity

For simplicity, we will discuss coronal malalignment at the knee, recognizing that varus or valgus deformities of the proximal femur or the ankle can also play a role.

When a deviation in the mechanical axis has been identified, the location of deformity (femur, tibia, and/or joint) can be determined by comparing selected radiographic measurements with normal values or with the contralateral extremity in patients with unilateral involvement (Fig. 37.3a, Table 37.1). These include the tibiofemoral angle, the mechanical (or anatomic) lateral distal femoral articular angle (mLDFA, aLDFA), and the mechanical proximal tibial angle (MPTA). Normative values are also available for sagittal alignment about the knee (Fig. 37.3b), including the anatomic posterior distal femoral angle (aPDFA) and the posterior proximal tibial angle (PPTA). Most deformities are in fact multiplanar.

Once the location of the deformity has been determined, the second step identifies the location of the deformity within the femur or tibia or both. This employs the CORA, or center of rotation of angulation. The CORA is essentially the apex of the deformity and is identified by drawing both the proximal and distal axes (mechanical or anatomic) to determine their intersection (Fig. 37.4). If they intersect at the site of defor-

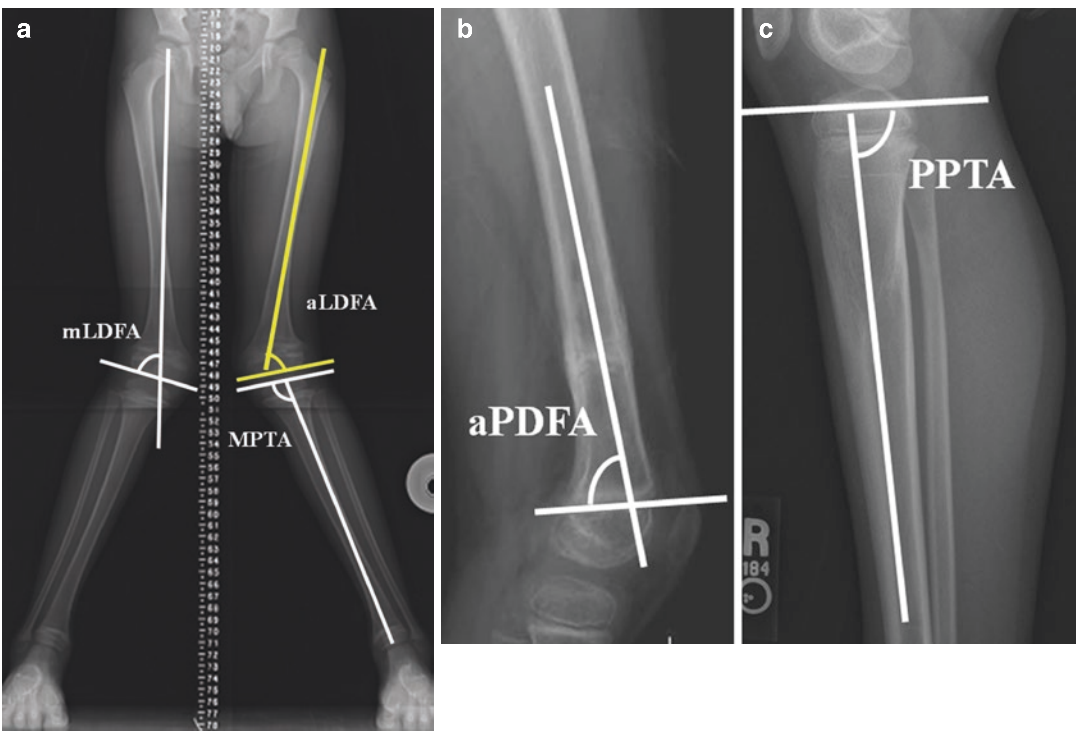

Fig. 37.3 (**a**) This radiograph of a patient with rickets demonstrates the anatomic (aLDFA) and the mechanical (mLDFA) distal femoral articular angles, as well as the mechanical medial proximal tibial angle (MPTA). (**b, c**) Measurements used to assess deformity in the sagittal plane include the anatomic posterior distal femoral angle (aPDFA) and the posterior proximal tibial angle (PPTA)

Table 37.1 Analysis of coronal and sagittal alignment

Joint	Measurement	Description	Normal values Mean (range)	Pathologic deviation
Coronal alignment	Mechanical lateral distal femoral angle (*mLDFA*)	Angle between the mechanical axis of the femur (center of hip to center of knee) and a line drawn along the distal femoral condyles	88° (85–90°)	↑ = Femoral varus ↓ = Femoral valgus
	Anatomic lateral distal femoral angle (*aLDFA*)	Angle between the anatomic axis (midshaft) of the femur and a line drawn along the distal femoral condyles	81° (79–83°)	↑ = Femoral varus ↓ = Femoral valgus
	Medial proximal tibial angle (*MPTA*)	Angle between tibial mechanical (same as anatomic) axis and a line drawn across the proximal tibial joint surface	87° (85–90°)	↑ = Tibial valgus ↓ = Tibial varus
	Joint line congruence angle (*JLCA*)	Angle between a line drawn along the distal femoral condyles and a line drawn along the proximal tibial joint surface	2° (1–3°) apex medial	↑ =Varus (wider laterally) ↓ =Valgus (wider medially)
Sagittal alignment	Posterior distal femoral angle (*PDFA*)	Angle between the mid-diaphyseal line of the distal femur and the sagittal distal femoral joint line (physis or physeal scar)	83° (79–87°)	↑ = Recurvatum ↓ = Procurvatum
	Posterior proximal tibial angle (*PPTA*)	Angle between the proximal tibial articular surface and the mid-diaphyseal line of the tibia	81° (77–84°)	↑ = Recurvatum (more anterior slope) ↓ = Procurvatum (more posterior slope)

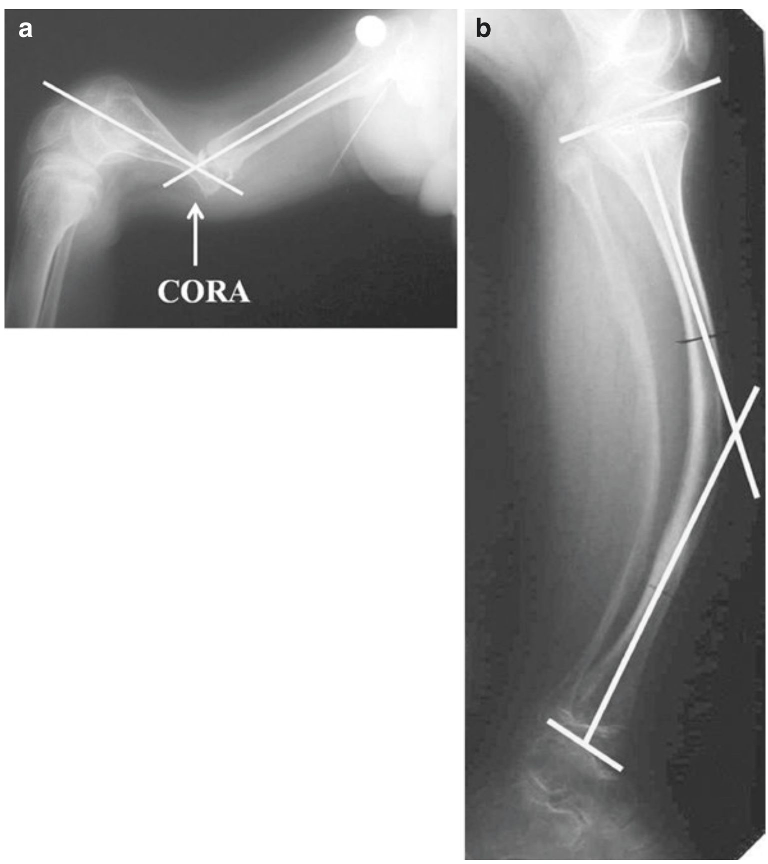

Fig. 37.4 The center of rotation of angulation (*CORA*). (**a**) The CORA for a transverse fracture lies at the site of deformity (fracture site) versus (**b**) a case of bowing in osteogenesis imperfecta in which the intersection of the mechanical axes of the proximal and distal tibia lies outside or away from the site of clinical deformity

mity as seen clinically, it is likely a uni-apical deformity, such as a malunited fracture, and correction would be performed at that location. If the lines do not intersect at the site of deformity, more than one CORA may exist, i.e., a multi-apical deformity or a uni-apical deformity with translational deformity.

Care should be taken to rule out compensatory deformities at the ends of the affected bone, especially in long-standing pediatric limb deformities. For instance, a child with a chronic midshaft varus deformity of the femur may develop a compensatory distal femoral valgus malorientation as a physiologic response to realign the mechanical axis of the lower extremity. Failure to recognize these secondary compensations before addressing the more apparent deformity may lead to iatrogenic "overcorrection" as the secondary deformity gets unmasked postoperatively.

Coexisting metabolic problems should be treated before correcting the deformity to limit the chance of recurrence. Hypercalcemia can be a problem in patients with rickets, especially if prolonged postoperative immobilization is required.

Surgical Correction of Angular Deformities

Angular deformity correction can be achieved by osteotomy, with acute or gradual correction, or by appropriately timed hemiepiphysiodesis, or guided growth. Most deformities are multiplanar, making a comprehensive assessment of the frontal, sagittal, and axial planes necessary. For instance, a child with Blount's disease typically has genu varum, along with procurvatum and internal tibial torsion secondary to the relative growth inhibition of the posteromedial portion of the proximal tibial growth plate.

Osteotomy

An osteotomy can be made by percutaneous drilling and manual osteoclasis, open drilling, use of osteotomes only, or an oscillating saw (irrigating to minimize thermal necrosis). Based on anatomic constraints and resources, fixation can be crossed K-wires or Steinmann pins, pins in plaster, staples, plates and screws, intramedullary nails, or external fixation. An acute opening wedge osteotomy with bone graft is useful when the limb is short, to gain or at least preserve limb length. Conversely, a closing wedge osteotomy will shorten the limb and does not require a graft and often provides greater stability at the osteotomy site. Oblique, dome, and step-cut osteotomies are described in Chap. 41.

Acute correction ≥20–30° carries a higher risk of neurovascular compromise, especially when correcting genu valgum with a proximal tibial osteotomy. In such cases consider prophylactic release of the common peroneal nerve and an anterior compartment fasciotomy. Gradual correction by serial casting or external fixation lowers these risks and allows correction of larger deformities, especially when associated with limb shortening.

If an osteotomy is made at the level of the CORA, ideally the deformity can be corrected by an opening or closing wedge osteotomy, as only angulation is required to restore the mechanical axis, i.e., no additional translation is needed. An example is a malunited transverse diaphyseal fracture of the tibia where the osteotomy would be performed at the fracture site. In contrast, when the osteotomy is made away from the CORA, both angulation and translation are needed to restore the mechanical axis. An example is a child with Blount's disease, in which the CORA is at the physis, but the osteotomy is performed distal to the CORA to prevent iatrogenic physeal arrest.

Hemiepiphysiodesis

An alternative to osteotomy is either a permanent or reversible hemiepiphysiodesis. This option is for milder deformities and requires >1–2 years of remaining growth. A correction of 0.5–1° per month can be anticipated, but the speed of correction depends on the growth potential of that particular physis, which may be less in patients approaching skeletal maturity and in those with skeletal dysplasias. Hemiepiphysiodesis can slow overall longitudinal growth of the operated bone, making careful, regular monitoring of both limb lengths and limb alignment, mandatory to achieve a satisfactory result.

Permanent hemiepiphysiodesis involves a partial surgical growth arrest by open or percutaneous techniques. A major challenge is predicting the appropriate time to perform the procedure in younger patients. In the open technique (Phemister), the physis is exposed, and a window of bone and physis is removed to 1 cm depth. The segment is rotated 180° and replaced, or a segment of metaphyseal bone is placed in the defect. For patients with <2 years growth remaining, permanent partial physeal closure may be more desirable than a reversible procedure.

Reversible hemiepiphysiodesis, or "guided growth," involves an extra-periosteal tether, staple, or plate, across the growing physis. The implant is removed once the deformity has been corrected or slightly overcorrected, although resumption of growth following implant removal is unpredictable. Gradual correction by "guided growth" has lower morbidity than osteotomy and can be an outpatient procedure. Follow-up must be assured, as the implant needs to be removed when correction has been achieved, and unplanned overcorrection is a risk especially in younger children.

Typically, three non-barbed (smooth) staples are used, spanning the physis in the distal femur and/or proximal tibia, or a single plate perpendicular to the physis with one screw above and one below (Fig. 37.5). Screw lengths are generally less than 50% of the width of the bone at that level. Staples have a greater risk of fracture or migration than plates, especially with staples made of contoured Steinmann pins or K-wires. The plate must be oriented centrally in the anterior-posterior plane to avoid inducing a sagittal plane deformity. In austere environments, a small plate cut to two to three holes may suffice (Fig. 37.6). In the absence of an image intensifier, a K-wire or a needle, confirmed with an intraoperative X-ray, can localize the physis. Avoid subperiosteal exposure of the physis or the perichondral ring, as an iatrogenic permanent growth arrest can occur. Rebound growth must be anticipated, and overcorrection of 3–5° may be indicated in children with sufficient growth remaining.

Bowing of the Lower Leg

Anterolateral bowing of the tibia, in which the apex is anterior and lateral, is usually noted in early childhood and often leads to progressive angulation and a fracture that is recalcitrant to healing. More than half the patients with this deformity have type I neurofibromatosis, and other manifestations of this disease should be sought (Fig. 37.7). This type of tibial bowing carries a poor prognosis, and the family should be counseled accordingly. Nonoperative management using a total contact brace with an anterior shell may delay or prevent a fracture. A tibial osteotomy through the dystrophic bone prefracture should be avoided as there is a high likelihood of nonunion. Once there is an established fracture, the goal is to obtain and maintain union at the pseudarthrosis, using sound biologic and mechanical principles, often with autogenous bone graft and intramedullary fixation.

Commonly used surgical techniques include resection of the pseudarthrosis with realignment and/or stabilization using either intramedullary fixation with autologous bone graft, with or without a circumferential periosteal graft from the iliac crest, bone transport with distraction osteogenesis along with prophylactic intramedullary fixation, or vascularized fibular strut grafting. A surgical cross-union between the tibia and fibula can minimize the chance of a refracture. In some refractory cases, amputation may be necessary, and the family should be informed of this possibility at the time of initial diagnosis.

Posteromedial bowing deformity of the tibia, apex posterior and medial, is almost always noted at birth and is associated with a calcaneovalgus foot deformity. This congenital anomaly has a relatively benign natural history with progressive improvement and mild residual angulation noted at skeletal maturity (Fig. 37.8). However, the

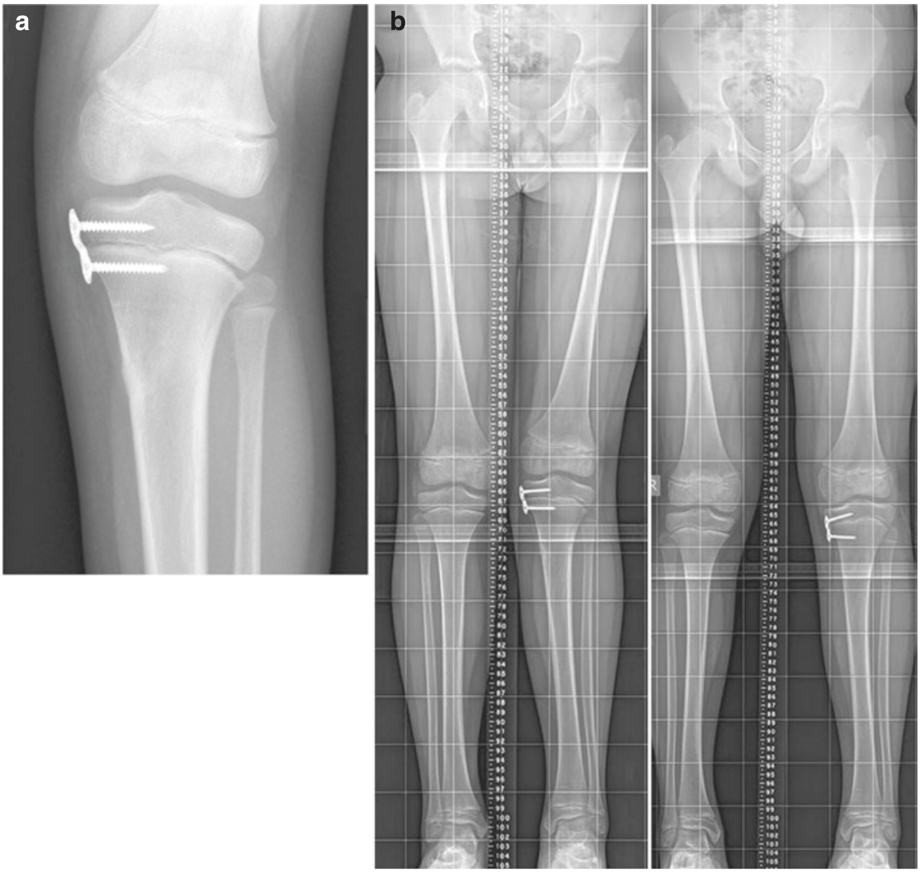

Fig. 37.5 A 12-year-old male presented 10 months after a left proximal tibial metaphyseal fracture that developed progressive valgus angulation. (**a**) A growth tether was created by placing a small plate with two screws. (**b**) Standing radiographs immediately after this "guided growth" procedure (*left*) and after 18 months (*right*) at which time the plate and screws were removed. Note the widened distance between screw tips, showing the differential growth and the resolution of the deformity

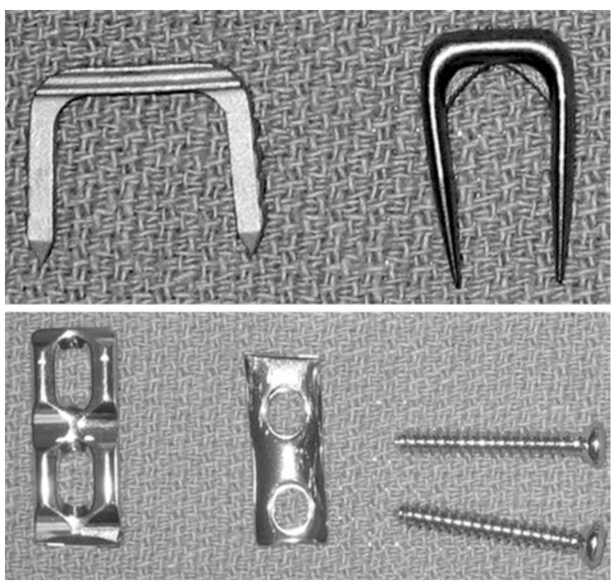

Fig. 37.6 Options for guided growth include staples and plates. In the absence of commercially available plates, reconstruction or semi-tubular plates can be cut and secured with cortical screws

Fig. 37.7 (**a**) An 18-month-old with anterolateral bowing of the tibia had (**b**) multiple café au lait skin lesions on his trunk consistent with the diagnosis of type 1 neurofibromatosis. (**c**) X-ray findings in severe congenital pseudarthrosis of the tibia and fibula with fracture and (**d**) clinical example of a neglected bilateral congenital pseudarthrosis with severe angular deformity

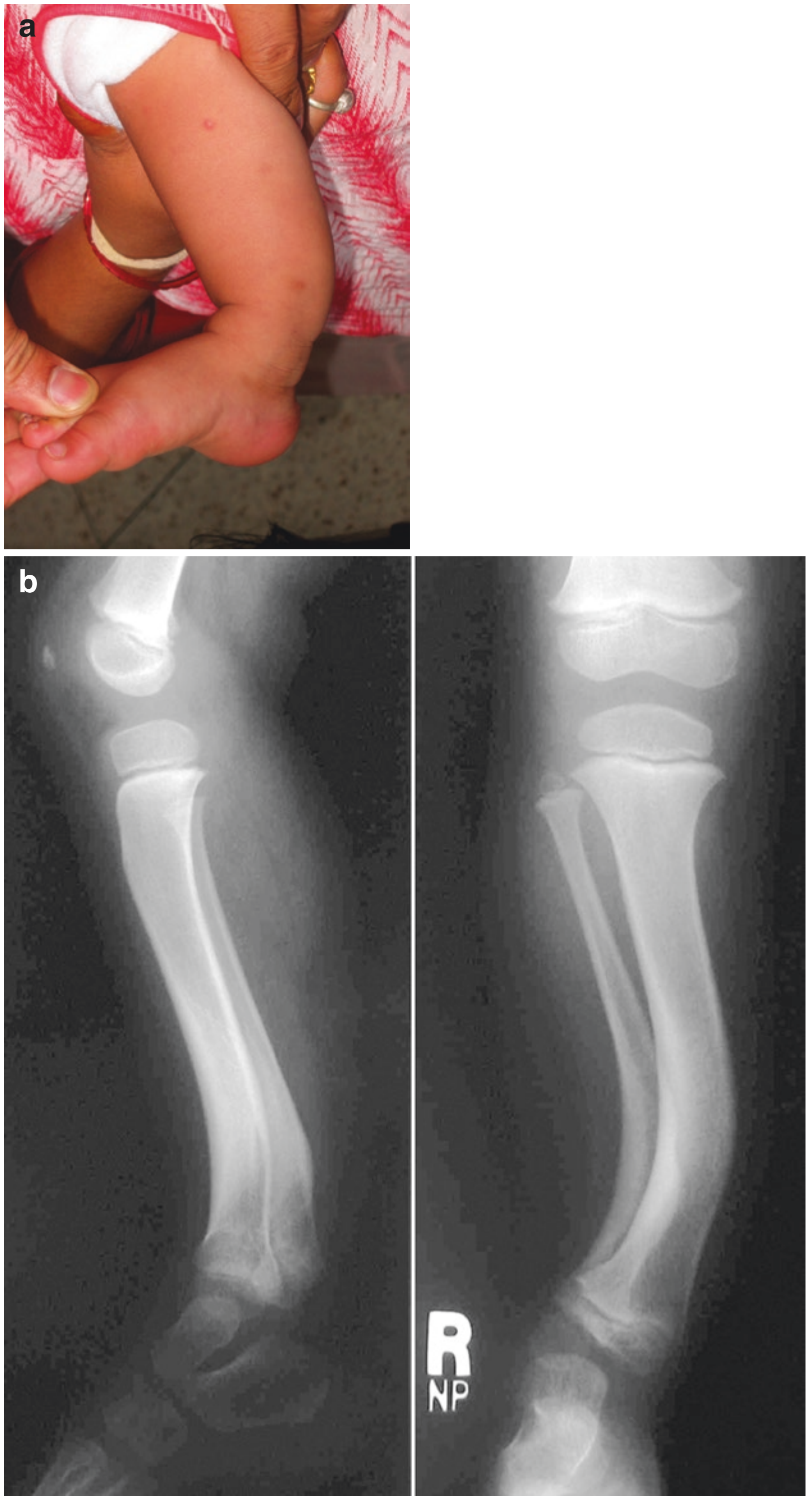

Fig. 37.8 (**a**, **b**) Clinical and radiographic findings associated with posteromedial bowing of the tibia

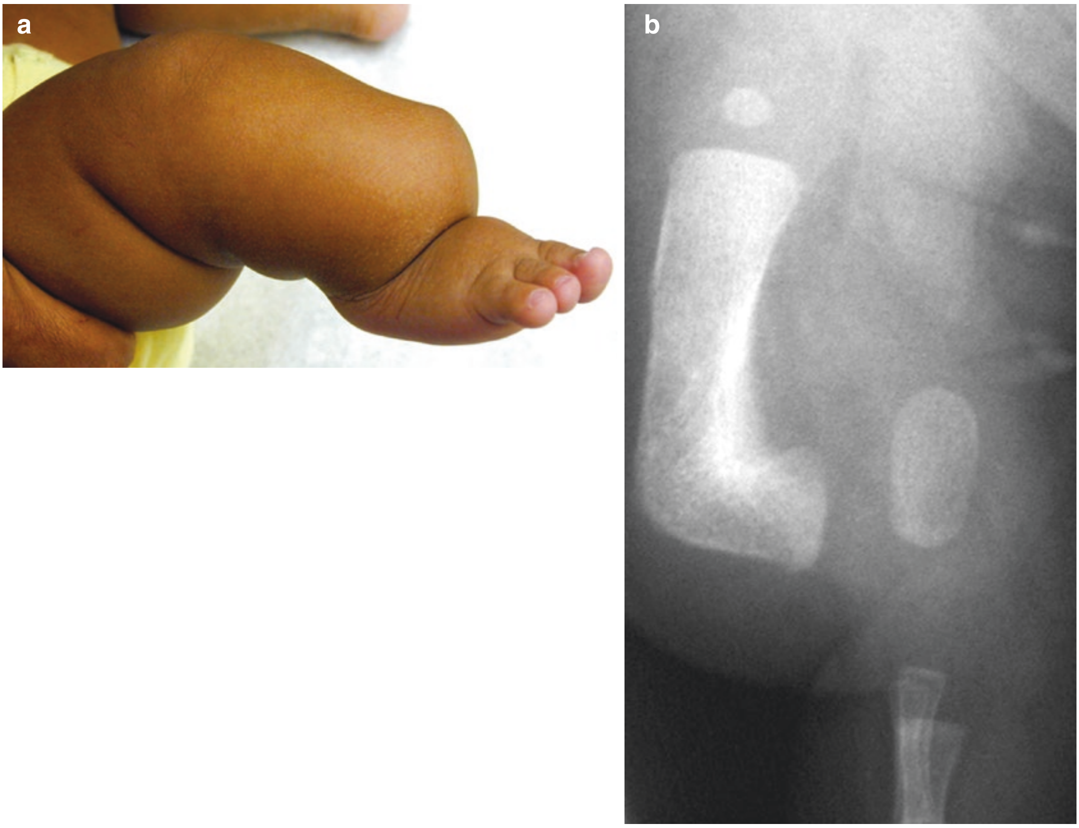

Fig. 37.9 (**a**, **b**) Clinical and radiographic appearance of a child with anteromedial bowing associated with longitudinal deficiency of the fibula

affected tibia grows more slowly than the contralateral side, requiring treatment for leg length discrepancy with either a contralateral epiphysiodesis or an ipsilateral limb lengthening with or without deformity correction.

Anteromedial bowing of the lower leg is often associated with longitudinal deficiency of the fibula (Fig. 37.9). Further evaluation often reveals skin dimpling at the apex of the tibial deformity, absence of one or more lateral rays of the foot, hindfoot valgus, and limb shortening. Besides tibial radiographs, a full-length AP radiograph of both lower extremities is useful as the deformity is often associated with congenital shortening or bowing of the femur, hypoplasia of the lateral femoral condyle, and cruciate ligament deficiency of the ipsilateral knee. The tibial deformity and the leg length discrepancy tend to increase with growth. Based on the anticipated function of the foot and projected limb length discrepancy at skeletal maturity, as well as psychosocial factors and cultural norms, the limb can either be lengthened (often in multiple episodes over the growing years, with or without contralateral epiphysiodesis) with angular correction or undergo amputation/reconstruction.

We must emphasize that limb lengthening reconstructive options are labor intensive and require months of active treatment and are subject to several complications, including pin site infection, refracture, and soft tissue contractures. Limb lengthening should only be considered when adequate local capacity is present to continue the treatment and follow-up.

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38 Developmental Dysplasia of the Hip

Richard M. Schwend

Introduction

Developmental dysplasia of the hip (DDH) encompasses a spectrum of physical and imaging findings from mild instability to frank dislocation. DDH is usually asymptomatic during infancy and early childhood, making a careful and specific physical examination critical. An early diagnosis markedly improves the prognosis, and health workers caring for newborns and infants at all levels should be trained in screening procedures.

The incidence varies from 1.5 to 25 per 1000 live births. The burden of disease in terms of disability-adjusted life years (DALYs) and years lived with a disability (YLD) is an important concept for DDH. However, there is little published data for this condition, nor is there information for how DALYs and YLD compare to other frequent pediatric lifelong conditions such as clubfoot, musculoskeletal infection, or trauma.

Risk factors include breech position, female, first born, and positive family history. The risk is increased in cultures that tightly swaddle infants with their hips extended (Fig. 38.1). In Africa infants are routinely carried with their hips abducted, and DDH is uncommon (Fig. 38.2).

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Looseness of the femoral head within the acetabulum is termed *instability*. Nonconcentric position is *subluxation*, and deformity of the femoral head and acetabulum is *dysplasia*. The natural history of instability noted in the first few weeks of life is typically benign, and many cases

Fig. 38.1 Extremely tight swaddling, in which the hips are forcefully maintained in extension and adduction, increases the risk of DDH. This infant is from the Amazon region of Ecuador, South America

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Fig. 38.2 (**a**, **b**) Carrying an older infant or young child on the back with hips abducted encourages healthy development of the hip. ((**b**) Courtesy of Byron McCord, MD)

resolve by 8 weeks of age. Conversely, the natural history of a hip that is subluxated or dislocated at walking age is poor.

With time, the child with DDH develops a limp, limb length discrepancy, and limited hip abduction. With bilateral dislocations the child will have lumbar hyperlordosis in addition to an abductor lurch (Fig. 38.3). With maturity the adult patient can develop painful, early-onset degenerative arthritis. Subluxation is often not as well tolerated as frank dislocation. Patients with balanced bilateral hip dislocations, or those who have not yet formed a false acetabulum, may have many years of pain-free ambulation. Other diseases of the hip may occur over the child's lifetime and confound the natural history and outcome, including trauma, sickle cell disease, tuberculosis, and Perthes [1].

Clinical Assessment

The physical examination in infants focuses on instability (Ortolani and Barlow maneuvers), whereas the exam in children older than 3 months identifies secondary changes including loss of passive abduction, shortening of the thigh with or without an extra thigh fold (Fig. 38.4), and leg

Fig. 38.3 This boy with bilateral DDH ambulates with an abductor lurch on both sides, in which his trunk shifts laterally over each hip during stance phase. He also has increased lumbar lordosis because of coexisting hip flexion contractures, noted by his protuberant abdomen

length discrepancy or limp. The Ortolani maneuver gently reduces the subluxated or dislocated femoral head into the acetabulum by hip abduction [2] and is the basis of the proper examination of the newborn hip. This maneuver begins with the hip in an adducted position. The examiner's hand holds the thigh loosely, with the index and middle fingers on the area of the greater trochanter and the thumb along the medial thigh. The hip is gently abducted while applying an anteriorly directed force through the trochanteric region, sensing whether the hip reduces. The Barlow

Fig. 38.4 Extra thigh fold on right from femoral shortening associated with dislocation

maneuver assesses whether a reduced hip can be displaced by placing the hip in adduction and gently applying a posteriorly directed force to the proximal anterior thigh.

Plain radiography becomes useful by 4–6 months of age, when the secondary center of ossification of the femoral head forms. Radiographic hip screening should be considered for the infant with risk factors for DDH or if diagnoses such as congenital short femur, proximal focal femoral deficiency, septic arthritis, or coxa vara are suspected.

The American Academy of Pediatrics recently published their revised guidelines for evaluation and referral of DDH in infants [3]. The authors believe screening is worthwhile to prevent a subluxated or dislocated hip by 12 months of age. The principles of prevention and early detection applied to all levels of health systems are outlined in Box 38.1.

Box 38.1 Principles for Evaluation and Referral of DDH

- Physical examination of the infant hip including the Ortolani test is the primary basis of early detection.
- Ultrasound to confirm dislocation, subluxation or dysplasia and the effects of treatment. Radiographs to confirm physical exam and for at risk hips when quality ultrasonography is not available (AP pelvic x-ray at 4–6 months).
- Minor hip abnormalities on physical examination or imaging can resolve spontaneously, but the infant should be followed up on an individual basis.
- Referral to an orthopedic specialist based on an unstable Ortolani exam alone at any age or asymmetric hip abduction after the neonatal period.
- Although no screening program can completely eliminate DDH, periodic hip examinations during infancy can greatly reduce the risk of a dislocated hip at 1 year.
- Tight swaddling of the hips should always be avoided and is most important for primary prevention [4].

Treatment

Early diagnosis and referral of DDH facilitates treatment by nonoperative measures, though this is uncommon in austere environments. If the diagnosis is established shortly after birth, treatment with a hip abduction device, such as a Pavlik harness, is recommended and can be used for infants up to 6 months of age. Orthotic treatment requires weekly monitoring but is discontinued after 2–3 weeks if a reduction is not achieved. Forced abduction should be avoided, given the high risk of avascular necrosis. If bracing fails or if excessive abduction is required to achieve reduction, a closed or open reduction and casting should be considered.

Between 6 and 24 months, closed reduction with percutaneous adductor tenotomy and a spica cast is often effective. The cast is typically worn for 3 months, after which nighttime splinting is used for a variable period of time. Risks of bracing, casting, and surgical treatment include stiffness, avascular necrosis (AVN), nonconcentric reduction, re-dislocation, and femoral nerve palsy.

Patients presenting after walking age with a limb length discrepancy, a limp, or toe walking may require open reduction of the hip with a capsulorrhaphy, femoral shortening osteotomy, and/or pelvic osteotomy (Fig. 38.5).

Open reduction removes barriers to a concentric reduction of the femoral head within the acetabulum by releasing the medial capsule and transverse acetabular ligament and removing the ligamentum teres and pulvinar. Femoral shortening reduces the risk of osteonecrosis in the older child. An intraoperative assessment of the degree of femoral anteversion will determine whether, and to what degree, the anteversion should be corrected. Femoral version varies considerably in patients with DDH, so no uniform recommendations can be made. Pelvic osteotomies include the Salter (redirectional) and the Pemberton. These procedures are technically demanding, and complications such as stiffness, osteonecrosis, or re-dislocation can result in outcomes that are inferior to observation alone (Fig. 38.6). Fifty percent of surgically reduced hips require further surgery, and repeat surgery in the older child is associated with poor results.

While there are no exact age criteria for when to surgically reduce a developmentally dislocated hip, we suggest that surgical reduction be avoided in patients older than 4–5 years with bilateral dislocations and older than 7–8 years with a unilateral dislocation.

In settings with limited resources, lack of expertise, and inadequate follow-up, the visiting volunteer surgeon should not perform this highly technical surgery in the older child with a dislocated hip, especially if previous surgery has failed or there is osteonecrosis. However, developing a trusting long-term relationship between an experienced visiting surgeon or organization and a committed and well-trained local surgeon can lead to an effective team to provide this high level of specialty care.

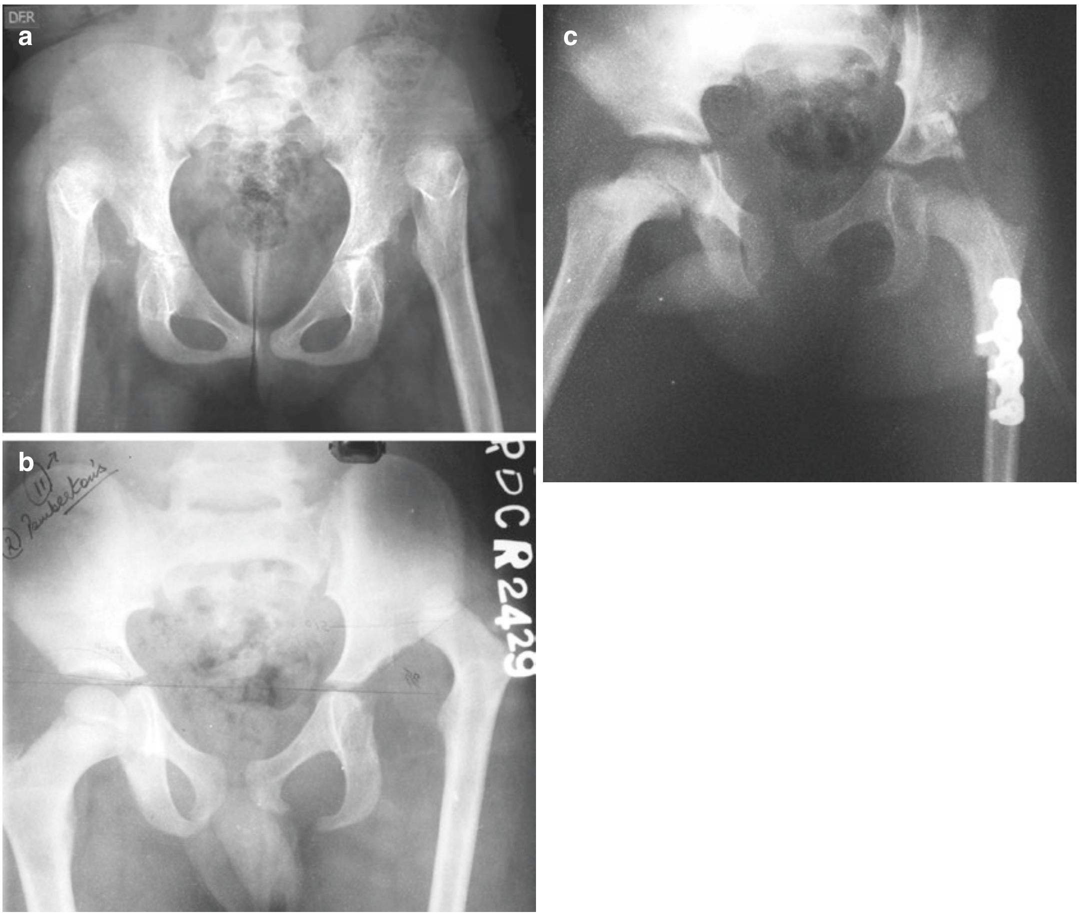

Fig. 38.5 (**a**) High bilateral hip dislocation with extreme acetabular and femoral head dysplasia in an older child should be left alone. (**b**, **c**) This unilateral dislocation in a younger child was treated surgically

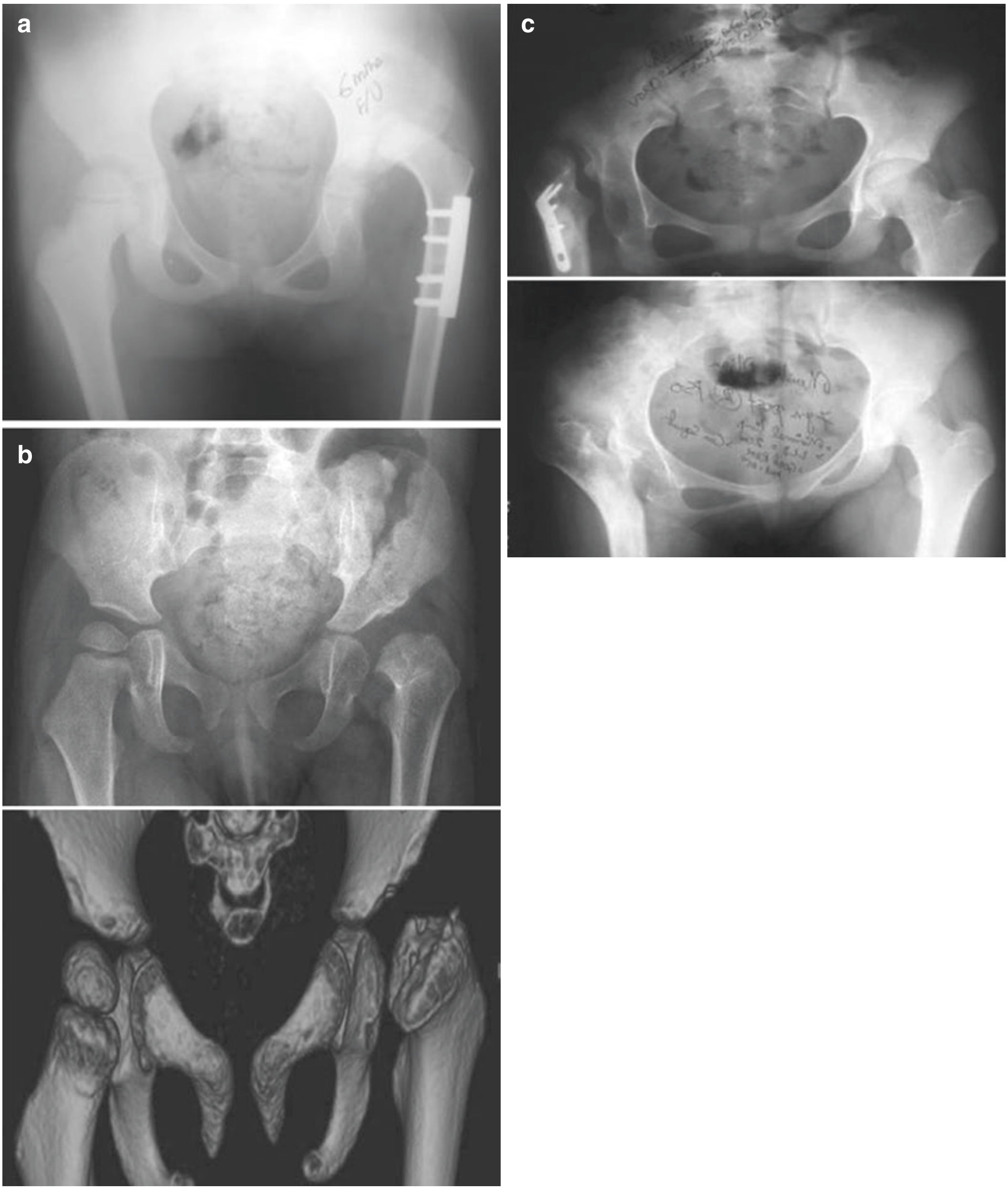

Fig. 38.6 (**a**) Open reduction and femoral shortening complicated by re-dislocation. (**b**) Successful closed reduction was complicated by avascular necrosis and deformity of the femoral head. (**c**) Chronic re-dislocation treated by pelvic support osteotomy

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39 Post-injection Injuries and Polio

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Introduction

Injection-induced injury during childhood is common. The usual clinical manifestations include (1) foot drop, (2) equinovarus, (3) buttock abscess, (4) gluteal fibrosis, and (5) quadriceps fibrosis. Injection injury is more likely in newborns and small babies where the skin and nerves are in closer proximity to each other than in older children. Many of the intramuscular injections given annually in developing countries are unnecessary yet are administered due to patient or family demand and caregiver overprescription. There is a prevalent belief in traditional settings that painful injections are more powerful and effective, even when adequate and recommended oral treatments are readily available. In many African languages the words for "fever" and "malaria" are the same, and all fevers are treated as if they were malarial.

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Post-injection Paralysis

Post-injection paralysis (PIP) has been called the "new polio" of Africa. The usual history for PIP is a young child with a febrile illness who receives an injection in the buttock or thigh for suspected malaria or other infectious illness. Although no longer the recommended first-line treatment for malaria, an injection of quinine is frequently given. It is painful, neurotoxic, and can cause local tissue necrosis, buttock abscess, muscle necrosis, fibrosis, and eventually gluteal contracture.

The child experiences immediate neurogenic pain, hypesthesia, and weakness or paralysis of the foot on the side of the injection, or symptoms can develop gradually over a week. While recovery is possible and typically progresses slowly over several months, permanent residual paralysis is common. The peroneal branch of the sciatic nerve, which lies lateral to the popliteal branch, is

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more vulnerable. The following muscles are affected, in the order from most common to least common: toe extensors, tibialis anterior, peroneals, tibialis posterior, toe flexors, and gastrocsoleus. There should be a sensory deficit in the first dorsal web space.

PIP is commonly confused with acute poliomyelitis. To differentiate, polio commonly retains function of the extensor hallucis longus, often shows weakness of quadriceps or glutei, and more importantly, has no sensory deficits.

Treatment of Post-injection Paralysis

Foot drop can be flexible or associated with varying degrees of fixed equinus contracture with or without hindfoot varus (Fig. 39.1). Flexible deformities present as impaired clearance during swing phase. Patients with fixed equinovarus bear weight on the lateral or dorsal aspects of the foot, causing trophic ulcers on the insensate weight-bearing surfaces (Fig. 39.2). Varus is secondary to peroneal weakness or paralysis with normally functioning toe flexors, with or without a normally functioning tibialis posterior. The tibialis posterior strength must be carefully assessed before it is transferred.

A surgical algorithm has been developed by the first author (JNP) for post-injection foot drop based on experience in Uganda (Table 39.1). Important pretreatment considerations include (1) degree and rigidity of heel varus, (2) presence of full passive range of motion, and (3) function of tibialis posterior.

A *flexible foot drop* can be treated with an ankle-foot orthosis (AFO). Routine posterior tibial tendon transfer is recommended, if its strength is grade 4–5, to restore muscle balance and minimize or eliminate the need for an orthosis. We suggest the posterior tibialis be brought subcutaneously to the dorsum and into a tunnel in the third cuneiform (Fig. 39.3) or sutured to the peroneus tertius. Transfer through the interosseous membrane is vulnerable to adhesions and may function as a tenodesis. When fixed deformity is present, preliminary soft tissue release, osteotomy, or arthrodesis may be necessary before tendon transfer.

Subtalar stabilization should be performed in all cases of tibialis posterior tendon transfer to

Fig. 39.2 Trophic ulcer in an insensate area of the foot in a patient with PIP

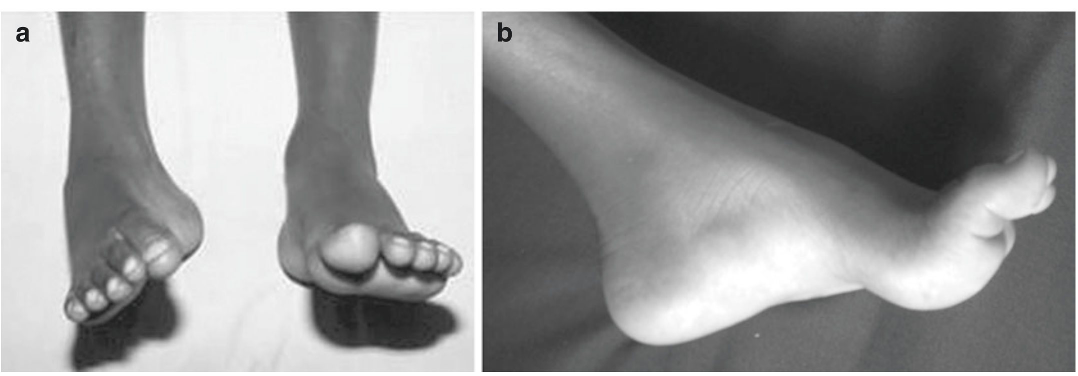

Fig. 39.1 (**a**, **b**). The typical appearance of foot drop following injection injuries. In these cases the deformities were mild and flexible on examination

Table 39.1 Treatment options for common foot deformities associated with post-injection paralysis and polio

Deformity	Causes	Treatment options
Equinus	1. Weak DF (TA, EHL, EDC, PB) 2. Strong PF (GS, FHL, FDL)	1. Gastrocsoleus lengthening
Equinovarus	1. Weak DF/EV (TA, EHL, EDC, peroneals) 2. Strong PF/IV (GS, FHL, FDL, TP)	1. TA transfer to middle cuneiform 2. TP transfer to third cuneiform 3. Subtalar stabilization
Equinovalgus	1. Weak DF/INV (TA) 2. Strong PF/EV (GS, TP, EHL, EDC, FHL,FDL, peroneals)	1. Gastrocsoleus lengthening 2. Transfer of peroneal tendons to dorsum of foot 3. Subtalar stabilization
Calcaneus or calcaneocavus	1. Weak PF [GS] 2. Strong DF/INV or EV	1. Ankle-foot orthosis 2. GS weak or absent: consider transferring all available muscles to calcaneus (PL, PB, TP, FHL) 3.Tenodesis of the tendoachilles to the fibula 4. Calcaneal osteotomy or triple arthrodesis
Cavovarus	1. Weak DF/EV [TA, peroneals] 2. Strong PF/INV (GS, TP, FHL, FDL ± EHL, EDC)	1. Percutaneous TAL, PF release 2. TP transfer to dorsum of foot 3. Subtalar stabilization 4. Transfer EHL to first metatarsal neck (Jones)

DF dorsiflexion, *PF* plantar flexion, *INV* inversion, *EV* eversion, *TA* tibialis anterior, *TP* tibialis posterior, *GS* gastrocsoleus, *PL* peroneus longus, *PB* peroneus brevis, *EHL* extensor hallucis longus, *FHL* flexor hallucis longus, *EDC* extensor digitorum communis, *FDL* flexor digitorum longus, *PF* plantar fascia

Fig. 39.3 The tibialis posterior is transferred subcutaneously, inserted through a drill hole into the third cuneiform, and secured with a suture through a button on the plantar surface of the foot

prevent the foot from collapsing into planovalgus. In children under 10 years, we recommend an extra-articular technique (Grice-Green or Dennyson-Fulford). The Dennyson-Fulford, performed using corticocancellous graft with internal fixation, produces more predictable results in our experience. A full preoperative range of subtalar motion is needed; otherwise, a posteromedial soft tissue release is necessary. A triple arthrodesis should be performed in adolescents and adults, with the advantage of making medial soft tissue release unnecessary and allowing superior correction in very stiff cases. If a bony procedure is needed, some surgeons prefer to stage the tendon transfer, to minimize disuse atrophy from prolonged casting (see Chap. 35 for further discussion on correction of foot deformities).

With an isolated soft tissue release or tendon transfer, patients require 4–6-week cast immobilization followed by an AFO (ankle-foot orthosis). Bony procedures require 8–12-week immobilization. Physiotherapy for tendon reeducation is necessary immediately after cast removal, and the AFO can often be discontinued when rehabilitation is completed, usually after 6 months.

Gluteal and Quadriceps Fibrosis

Fibrosis of the gluteal or quadriceps muscles is associated with injections into the muscles, often multiple. Numerous drugs have been implicated, but in malarial areas, quinine is the main culprit. It is thought that quinine is a potent producer of muscle necrosis with subsequent fibrotic contracture. In certain Asian countries, penicillin has been implicated. Gluteal fibrosis (GF) is thought to be caused by microabscesses in the setting of substerile technique, the intrinsic fibrosis-inducing effects of particular medications, mechanical disruption of the muscle tissue planes, or a combination of these and other factors that are not well understood.

Patients diagnosed with GF present clinically with an awkward gait, especially with running and obligate external rotation and abduction of the hip on attempting hip flexion due to limitation of gluteal excursion. They show a combination of muscle wasting (Fig. 39.4) and fibrotic hypertrophy. They cannot sit comfortably or squat except with the legs externally rotated (Fig. 39.5). The condition is usually described as bilateral and frequently diagnosed in school age children. GF has been reported from throughout the world, with high rates noted particularly in China, Taiwan, and recently in areas of sub-Saharan Africa.

Surgical treatment of GF includes a variety of open surgical techniques in the lateral decubitus position with intraoperative identification and release of fibrous bands. Incision placement varies, ranging from just posterior to the greater trochanter to directly over the buttock. Full-thickness skin flaps are raised exposing the gluteus maximus and notable fibrotic bands. The gluteus maximus, gluteus medius, and gluteus minimus are sequentially released with diathermy while protecting the sciatic nerve (Fig. 39.6). Complete release is achieved when hip flexion greater than 90° and internal rota-

Fig. 39.5 Patient with gluteal fibrosis forced to squat in the “butterfly position” with lower extremities externally rotated due to the contracture

Fig. 39.4 Patient with gluteal fibrosis and marked muscle atrophy of the gluteal muscles

Fig. 39.6 The surgical scar following release of gluteal contracture

tion beyond neutral are possible. Range of motion exercises, crutch walking, and gait training are started as soon as possible; rehabilitation takes 2–3 months.

With quadriceps fibrosis and contracture, the child walks with a stiff knee gait. A modified Judet quadricepsplasty is recommended. Proximal release is a critical component, as distal release alone is less effective and has a higher incidence of weakness, extensor lag, or quadriceps rupture. A lateral incision extends proximally from the distal femoral metaphysis. The vasti are released extra-periosteally, and multiple transverse incisions may be necessary in the iliotibial band and vastus fascia. The rectus femoris is released from the anterior inferior iliac spine through a separate anterior incision.

The contracture can be limited to just the rectus femoris, as demonstrated in the Duncan-Ely test (with the patient prone, the knee is flexed, causing the pelvis to lift from the table). In this case the rectus femoris is released before considering quadricepsplasty. Postoperative therapy involves immediate passive range of motion and early active range of the knee.

Residua of Acute Poliomyelitis

Introduction

Besides the several hundred new cases of acute poliomyelitis each year, thousands of patients suffer from the residua of the disease. Polio is an enterovirus infected via the fecal-oral route. Most infected patients will have a self-limited diarrhea but can shed virus from the GI tract for up to 1 month. Approximately 50% of those infected will show no clinical illness. Another 48% will have an abortive illness consisting of muscle aches or headaches characteristic of an irritation of the meningeal linings of the brain and spinal cord. Only 2% will develop typical flaccid muscle paralysis.

In those with paralysis, the virus enters the central nervous system through peripheral nerve roots and migrates proximally to the anterior horn cells of the spinal cord, causing nerve cell injury and flaccid paralysis. Following the acute illness, characterized by high fevers, muscle pain, and varying degrees of paralysis, two-thirds of patients will recover, usually within the first 12 months, with a higher incidence of recovery in children compared to adults.

Polio presents as a nonprogressive, asymmetric flaccid motor paralysis or paraparesis. The diagnosis requires a history of a febrile illness, exam with normal sensation, no spasticity, and no bowel or bladder involvement. The differential diagnosis includes (1) post-cerebral malaria (spasticity, cognitive abnormalities); (2) Guillain-Barré or transverse myelitis (symmetric flaccid paralysis, sensory abnormalities); (3) konzo, lathyrism, and tropical myelopathy (spasticity, ataxia); (4) Burkitt's lymphoma of spine, spinal tumors, and spinal tuberculosis (progressive, spasticity before flaccidity, bowel and bladder abnormalities, sensory involvement); and (5) post-injection paralysis.

Principles for polio treatment can be applied to other flaccid paralyses, remembering that the goal of surgery is functional restoration. Patient selection is critical, and surgical treatment must be complemented by rehabilitation and bracing.

Contractures are caused by muscle imbalance and positional or mechanical factors but also by interstitial fibrosis from the inflammatory myositis during the initial viremic infection. Contractures of the tensor fascia femoris and iliotibial band (ITB) are frequent and all but pathognomonic for polio confirmed with the Ober test. This test is performed with the patient lying on their uninvolved side, with the uninvolved knee and hip flexed. While stabilizing the pelvis, the leg to be tested is extended, internally rotated, and adducted toward the table (Fig. 39.7). The abduction contracture prevents the leg from reaching the Table.

A full examination in a polio or other paralysis includes manual muscle testing of the upper and lower extremities and examination of the trunk and joint range of motion.

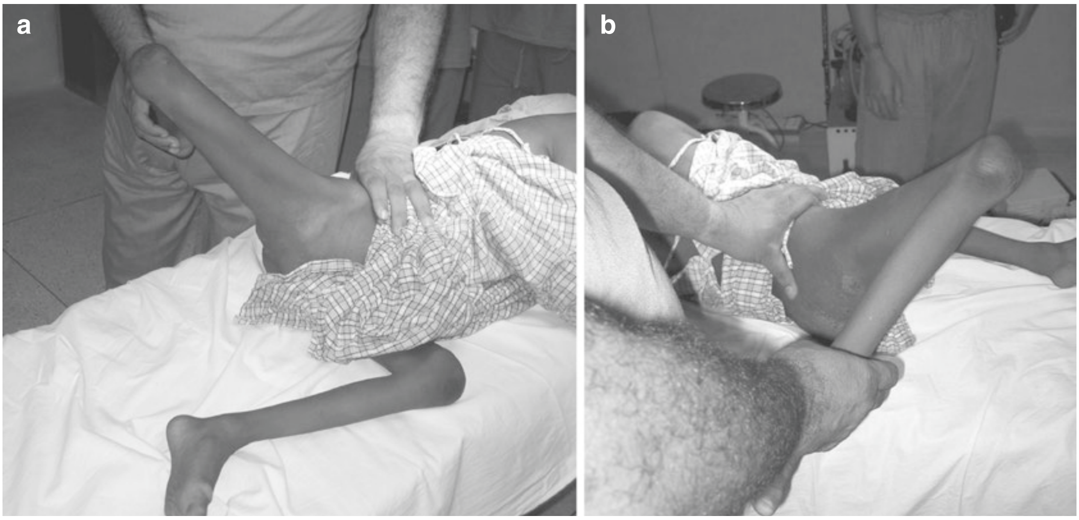

Fig. 39.7 The Ober test. (**a**) The patient is positioned on his/her side, with the leg to be tested facing upward. The other leg is flexed maximally at the knee and the hip. The leg to be tested is extended, internally rotated, and adducted. In this example (**b**) the thigh fails to adduct even down to neutral, suggesting a significant contracture of the iliotibial band

Manual muscle testing values:

- 0 = no perceptible active muscle contraction
- 1 = muscle contraction palpable as an isolated twitch, but no motion of the joint
- 2 = active motion through full possible range of motion with gravity eliminated
- 3 = active motion against gravity only, without resistance
- 4 = full range of active motion against some resistance
- 5 = full range of active motion against full resistance

When resources are scarce, patients must be appropriately triaged to different levels of care. Some patients have the potential to be community ambulators, while others should be given a wheelchair and other assistive devices rather than undergo complex orthopedic procedures (Fig. 39.8).

Common Patterns of Deformity

Though a broad spectrum and unique combinations of muscular weakness or paralysis are seen in patients with poliomyelitis, common patterns of deformity are (1) the crawler, (2) single-leg involvement (dangling leg syndrome), and (3) equinus (Fig. 39.9a–c). Severe cases with upper extremity weakness or trunk involvement with scoliosis are uncommon (Fig. 39.9d, e).

Crawlers typically have bilateral severe lower extremity paralysis with minimal or no upper extremity involvement. Contractures include hip flexion/abduction, knee flexion (often with external rotation), and ankle equinus. This group of patients often carries a significant social stigma as they have to use their upper extremities to maneuver into latrines and their hands are chronically dirty, which prevents access to communal meals.

Patients with single-leg involvement typically have severe paralysis of one lower extremity, with weakness and contractures similar to those described for the crawler. They often walk with a stick and the leg dangles.

Equinus deformity can be due to either paralysis of the dorsiflexors with functional plantar flexors, giving a dynamic imbalance, or paralysis of both muscle groups with a plantar flexion contracture. Extensor hallucis longus function is

Fig. 39.8 (**a**). A knee ankle foot orthosis (KAFO), also called a caliper. (**b**) Patient wearing a leather and metal KAFO attached to an open-toed boot

often preserved, as its innervation originates from several root segments in the spine. Pure equinus is most common, but equinovarus or equinovalgus can occur.

Priorities for Treatment

The goals of treatment include (1) ambulation, (2) prevention of deformities during growth, (3) decreased bracing, (4) addressing the upper extremity, and (5) treatment of spinal deformity. If the arms are weak or there is poor trunk control and scoliosis, provide a wheelchair. Adequate triceps and trunk strength are essential for crutch use and must be assessed preoperatively to define the patients who will benefit from lower extremity surgery. Assess triceps and deltoid strength by having the child raise his arms overhead and lifting his bottom off the chair by pushing down with both arms. If the child can kneel without using his hands, the hip extensors are at least grade 4 with a good potential for ambulation.

Fig. 39.9 The most common presentations are (**a**) the crawler, (**b**) dangling leg syndrome, and (**c**) equinus. (**d**) In cases with greater severity, there may be significant weakness of the trunk and upper extremities that preclude the use of crutches or assistive devices. (**e**) This man with flail lower extremities used a stool as an assistive device and locked both knees in hyperextension for stability

Typical treatments include the release of contractures around the hip, knee, and ankle, followed by an AFO or KAFO (knee-ankle-foot orthosis) typically made from thermoplastic materials or a caliper, made from leather and metal. Post-op rehabilitation is often begun with a walker, graduating to standard axillary crutches followed by forearm crutches (Lofstrand) as strength and confidence improve. Comfortable fitting with a caliper may require surgical treatment of foot deformities and correction of valgus knees and external tibial torsion.

In some cases the goal is to reduce the need for bracing, initially requiring attention to foot deformities by soft tissue release, tendon transfer, osteotomy, or arthrodesis. Procedures at the knee such as extension osteotomy and hamstring transfer may enable the caliper to be discontinued. However, hamstring transfer can weaken knee flexion and impair function of activities performed close to the floor, such as sitting or squatting at in-ground toilets.

As a child approaches skeletal maturity (15–16 years), opportunities for correction diminish rapidly; complication rates are high, and rehabilitation is long and difficult. Functional decline is a significant risk, limiting the ability to crawl, particularly after knee corrections. It is often pragmatic to accept the deformities and accommodate them with a wheelchair or tricycle.

Surgical Principles and Techniques

Correction of Hip and Knee Contractures

Methods to straighten the knee include passive stretching exercises, traction, surgical release of contracted soft tissues, osteotomy, or serial casting/cast wedging alone or in combination. Relative contraindications include knee contractures of more than 90°, marked external rotation (Fig. 39.10) posterior subluxation of the knee, or severe bilateral hip contractures.

Nonoperative measures should take care to counteract posterior subluxation of the tibia during manipulations and plastering (Fig. 39.11). The first author (JNP) has developed a plaster wedging technique that allows the tibia to be translated anteriorly to prevent this (Fig. 39.12).

Indications for serial wedging include (1) patients <12 years old, (2) feet do not require surgery, (3) knee contractures less than 60°, and (4) no significant posterior subluxation or external tibial rotation.

Procedure: (1) Internally rotate the tibia to correct any external rotation, (2) apply a long leg cast with molding above the patella to gain extension while simultaneously translating the proximal tibia anteriorly, (3) wedge the cast after 1 week, and (4) after two wedgings, apply a new cast. When serial casting is used to achieve fur-

Fig. 39.10 Flexion contractures at the knee may be accompanied by external rotation at the knee joint and posterior subluxation of the proximal tibia

Fig. 39.11 When stretching or serial casting a fixed knee flexion contracture, care should be taken to simultaneously translate the proximal tibia anteriorly while pushing down on the distal femur to avoid posterior subluxation

ther correction after surgical releases, the first cast is applied 2 weeks postoperatively, with repeat wedgings every 10–14 days thereafter. Each wedging corrects about 10°.

Contractures at the hip and knee typically require surgery, followed by stretching, traction, or serial wedging plasters, to achieve full correction. In general nonfunctional muscles are released and functional ones are lengthened. While release of hip and knee contractures can be completed in one setting, our opinion is that the knees and ankles should be treated first as residual knee flexion increases the risk of recurrent hip flexion contracture. While percutaneous techniques have been described by Huckstep, in this chapter, we will focus on open surgical lengthenings.

Stage 1: ankle contractures. The equinus deformity is addressed by tendoachilles lengthening (TAL) performed percutaneously in mild deformities or by open lengthening with release of tibiotalar and subtalar joints for more severe contractures. A Lambrinudi triple arthrodesis may be necessary when a TAL is insufficient (see Chap. 35 for the technique). It is wise to leave a few degrees of residual equinus to help stabilize the knee by driving it backward during stance phase. If the leg is completely flail without good hip extensors, it is unlikely the child will walk without a caliper, in which case the ankle can be brought to neutral. Residual equinus can also compensate for a short limb.

Knee contracture. The knee release starts with excision of the iliotibial band and lateral intermuscular septum, the Yount procedure (Fig. 39.13). Sometimes the hip contracture will improve with sectioning the iliotibial band as part of this release. With marked external rotation and/or subluxation of the knee, the biceps femoris is also released. Less commonly, releases or lengthenings of the semitendinosus, semimembranosus, and gracilis are performed through a medial incision. We do not recommend posterior capsulotomy, though one might consider releasing both heads of the gastrocnemius if the soleus is strong. When correcting a bilateral deformity >20° in older patients, femoral shortening or a distal femoral extension osteotomy with shortening may give the best results.

Stage 2. A hip flexion/abduction release is required if there is marked lumbar lordosis or an unstable forwardly pitched body position during stance. It can be done once the knee is straight and the child is walking in calipers, usually 3–6 months after the first phase.

An open hip release, the Ober procedure (Fig. 39.14), begins with a longitudinal incision in the interval between the sartorius and the tensor fasciae latae. The lateral femoral cutaneous nerve is identified before releasing these two muscles and the anterior part of the glutei. The release should not extend posteriorly beyond the trochanter as this will weaken the hip extensors. The rectus femoris release follows. Anterior hip capsule release is usually unnecessary. Full correction is rarely achieved at surgery.

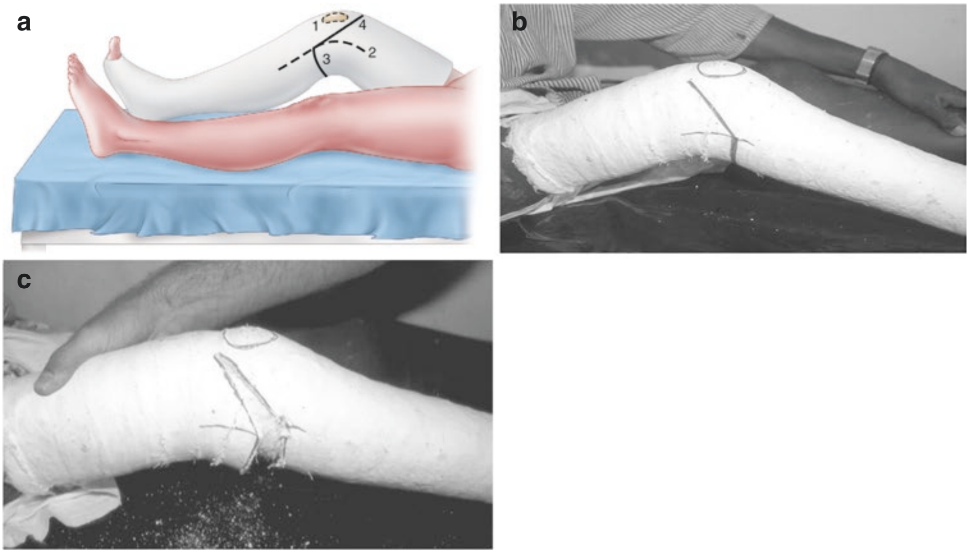

Fig. 39.12 Serial wedging for knee flexion contractures. (**a**, **b**) Lines drawn on plaster for orientation and cutting. (1) Outline of the patella, (2) *dotted line* marks the midline on lateral and medial sides. (3) About 1 in. distal to the patella, draw a half circle around the posterior half of the plaster connecting the two midline markings. This line represents the posterior knee joint. (4) From both sides of the proximal pole of the patella and 2 in. apart, mark a line to meet line (3) at the midline. (**c**) Cut the plaster, leaving an intact hinge between the anterior cuts proximal to the patella. This hinge serves as the center of rotation, proximal and anterior to the tibia. Gently straighten the knee/plaster, noting how the tibia shifts anteriorly, and fill the gap with cotton wool or cork. Overwrap with one or two rolls of plaster. After 5–10 days, the plaster can be wedged again by removing the last rolls of plaster revealing the initial drawings. Never wedge the plaster more than two times; replace the cast instead. When the tibia is in extreme external rotation (as in polio), the center of rotation on the plaster should be positioned proximal and medial to the patella

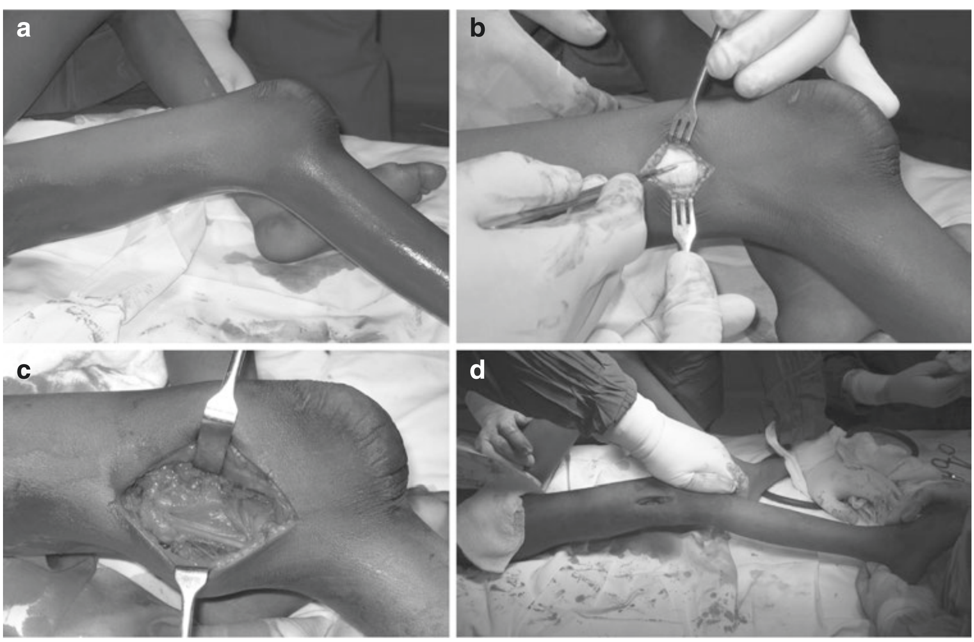

Fig. 39.13 (**a**) A fixed knee flexion contracture with mild posterior subluxation of the tibia. (**b**, **c**) The distal release (Yount procedure) begins with a longitudinal incision through which the iliotibial band and the intermuscular septum are resected. (**d**) Correction achieved on the table. Residual deformity will be corrected by stretching or serial casting

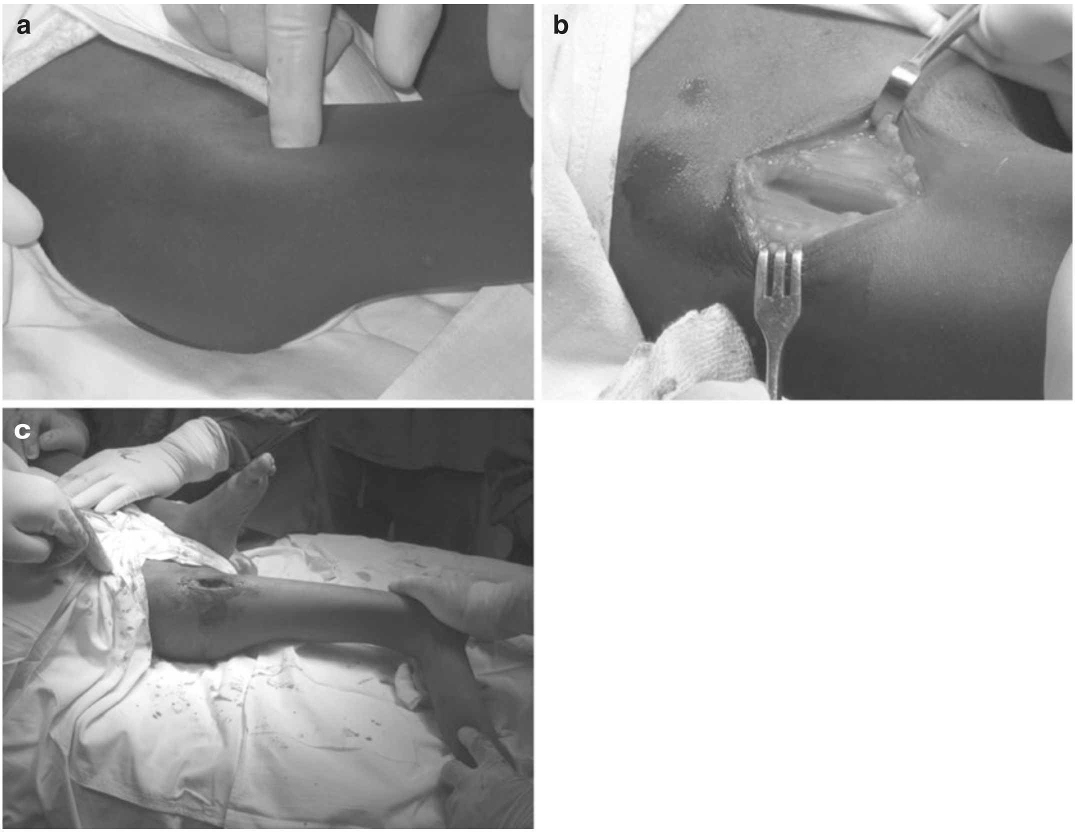

Fig. 39.14 The Ober procedure is a proximal release. (**a**) The interval between the sartorius and tensor fasciae latae is palpated. (**b**) A longitudinal incision is made in the interval. The tensor and sartorius and the glutei, to the greater trochanter, are released (but not posterior to the trochanter to preserve power of the hip extensors). (**c**) In this case correction was achieved on the table

If the hip and knee releases are performed simultaneously, traction can be useful to gradually achieve full correction (Fig. 39.15). A distal tibial traction pin is placed for longitudinal traction and a proximal tibial traction pin for an anterior vector to counteract posterior subluxation of the tibia. Usually 3–6 weeks of traction are required, after which patients can be mobilized in KAFOs.

In association with hip and knee contractures, a variety of foot deformities occur depending upon the pattern of weakness, the most common of which are equinus and equinovarus (Table 39.1, Fig. 39.16). The main principles are as follows:

- Release contracted soft tissues
- Stabilize the subtalar joint
- Transfer muscles to balance the foot and ankle

Achieving muscle balance is critical even when a triple arthrodesis is performed. The same procedures as described above in treatment of drop foot due to PIP are used.

Fig. 39.15 (**a**, **b**) This 18-year-old had severe flexion deformities at the hip and knee. (**c**) He was treated by proximal and distal soft tissue releases and skeletal traction. (**d**, **e**) The deformities corrected gradually and (**f**) he was mobilized with KAFOs and a walking frame

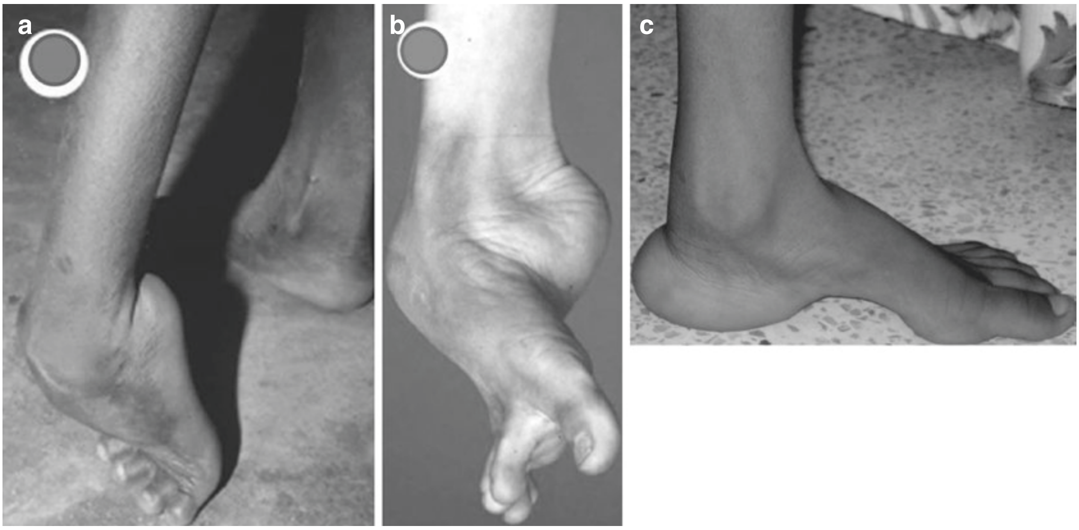

Fig. 39.16 Typical foot deformities include (**a**) equinus, (**b**) equinovarus, and (**c**) calcaneus

Miscellaneous Considerations

Quadriceps weakness or paralysis is common, and patients compensate with a "thigh-hand" gait, in which manual pressure on the anterior distal thigh facilitates knee extension (Fig. 39.17). A forward leaning trunk also compensates by keeping the ground reaction force anterior to the knee. The presence of a fixed flexion contracture precludes locking the knee into a stable position. The most appropriate treatment depends on the degree of weakness and the strengths of the gastrocsoleus and the gluteal muscles.

Patients with mild to moderate weakness, no knee flexion contracture, and adequate strength of the hip and ankle muscles may compensate adequately. A caliper is an excellent choice when motion is full or flexion deformity is <20°. A hamstring tendon transfer can be considered if there is full range of motion at the knee, at least 4/5 strength on manual motor testing the hip flexors and gastrocsoleus, normal patellofemoral mechanics, and normal limb alignment. The most successful technique is transfer of both semitendinosus and biceps femoris to prevent lateral patellar subluxation by solitary pull of the biceps femoris. Patients will lose active knee flexion, which can cause additional disability, especially with activities performed at ground level. In patients with a coexisting tendoachilles contracture, there is a risk of destabilizing the knee if the tendoachilles contracture is also corrected. It is typically safe to do a TAL when the quadriceps is grade 3 strength or better but wise to leave some mild equinus when in doubt.

Genu recurvatum or hyperextension of the knee during stance phase can be secondary (Fig. 39.18) to excessive stretching of the posterior soft tissues and is commonly associated with weakness of the gastrocsoleus, quadriceps, and hamstrings. The most common treatment is a KAFO or caliper and equinus correction.

Genu recurvatum also results from bony deformity, particularly an anterior slope of the tibial plateau. Typically, gastrocsoleus and hamstrings have normal strength, quadriceps are weak, and equinus is present. The equinus prevents the tibia from advancing over the foot in stance phase, driving the knee into extension. While an orthosis will suffice in most cases, a flexion osteotomy of the distal femur may be necessary. Osteotomy of the proximal tibia carries an increased risk of neurovascular injury.

Leg length discrepancies are common, caused by absolute bony shortening, infrapelvic obliq-

Fig. 39.17 The thigh-hand gait is a compensatory mechanism for quadriceps weakness or paralysis, to help lock the knee into extension during stance phase

Fig. 39.18 Knee hyperextension may be due to soft tissue laxity or may be associated with recurvatum of the proximal tibia. Equinus is usually observed

uity (hip abduction or adduction contracture), and/or suprapelvic obliquity (scoliosis) (Fig. 39.19). Slight shortening may be an advantage if the limb requires a brace, to provide clearance during swing phase. Treatment is individualized and can include contracture releases, epiphysiodesis, or limb lengthening. Epiphysiodesis may not be viewed favorably by the family as the surgery is done on the normal limb.

Hip instability, either subluxation or dislocation, can result from muscle imbalance or pelvic obliquity (infrapelvic or suprapelvic). When required, treatment should be directed to the primary pathology. Correction of hip abduction contracture by soft tissue releases may improve hip alignment and the compensatory scoliosis. For persistent hip instability, reconstruction by femoral and/or pelvic osteotomy with open reduction can be considered, recognizing a significant risk of recurrence due to weakness of the surrounding muscles.

Upper extremity involvement is less common than lower extremity involvement and seldom requires surgery. Patients with a flail shoulder will benefit from a shoulder fusion, ideally between the ages of 6 and 8. The technique involves peeling off the articular cartilage and fixing the joint with wires that are later removed, preserving the physis and longitudinal growth. The most common procedures at the elbow are to restore elbow flexion by appropriate tendon

Fig. 39.19 Polio can be associated with a significant reduction in size of the involved extremity. (**a**–**c**) In this case of a flail right leg, there is significant leg length discrepancy due to bony shortening. Even the foot is smaller. (**d**, **e**) Leg length discrepancy can also be "apparent," due to contractures and/or angular deformities. Components might include absolute bony shortening, right hip adduction contracture (infrapelvic obliquity), left hip abduction contracture (infrapelvic obliquity), and left lumbar scoliosis (suprapelvic obliquity). The left lumbar curvature might also be compensating for the infrapelvic obliquity

transfer. Release of a forearm pronation contracture may also improve function.

Scoliosis is seen in up to 25% of polio patients, especially those with greater degrees of neurologic impairment. It may be due to asymmetric or global trunk weakness or as compensation for hip contractures. Progressive curves may impair sitting balance and ventilatory function. Non-ambulators typically have a collapsing C-shaped thoracolumbar or lumbar curve with pelvic obliquity. When a hip contracture and scoliosis coexist, we recommend correcting the hips first. A brace may serve as a temporizing measure to improve sitting balance and upper extremity function and possibly delay progression. Once a progressive, symptomatic curve is felt to warrant stabilization (>40–60° Cobb angle), an instrumented posterior spinal arthrodesis from T2 to the pelvis is required if the resources are available.

Post-polio syndrome: About 40% of adults who had polio as a child develop symptoms later in life that include increasing weakness in their previously affected muscles, fatigue, muscle pain, cold intolerance, muscle atrophy, and joint pain. This often develops around 30–40 years after their initial illness.

Polio-like syndromes: In recent years, there have been cases of children presenting with polio-like syndromes in numerous places throughout the world. This condition is now referred to as "acute flaccid myelitis" (AFM). Presenting symptoms are similar to polio, but upper extremity involvement is more common than is seen in polio. An outbreak of both polio and polio-like syndrome occurred in Tajikistan in 2014 (over 400 cases of polio and 200 cases of AFM), and ~346 cases have been identified in the USA between August 2014 and August 2018.

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40 Cerebral Palsy and Other Neuromuscular Conditions

Bibek Banskota, Michelle Foltz, Richard A. Gosselin, and David A. Spiegel

Introduction

The burden of cerebral palsy (CP) is large, with an annual incidence of 2–3 per 1000 live births worldwide. Most cases remain without a formal diagnosis, and while a subset of patients succumb to associated medical comorbidities, especially pulmonary, many survive with varying degrees of disability in environments with little access to health services or social welfare infrastructure. CP is a nonprogressive developmental disability of motion and posture arising from injury to the immature brain. It presents on a spectrum from the mildly involved hemiplegic child to one with spastic quadriplegia who has multiple contractures that interfere with ambulation, positioning, and care and may have scoliosis, mental retardation, and coexisting medical problems (Fig. 40.1). Non-orthopedic abnormalities are common and often unrecognized.

In contrast to economically developed countries where CP is commonly associated with prematurity and low birth weight, most cases in the developing world are due to inadequate antenatal care, unsupervised home deliveries, and a lack of access to emergency obstetric interventions such as cesarean section. Postnatal infections (encephalitis, meningitis) and kernicterus (neonatal jaundice) are also important causes.

Evaluating patients with CP requires a detailed birth history, identifying delays in neurologic development and documenting upper motor neuron findings including clonus and hyperreflexia. While the neurologic impairments are static, secondary musculoskeletal abnormalities progress with growth and include myostatic muscle contractures and torsional deformities of the femur and tibia, as well as foot deformities such as equinus, equinovarus, and equino-planovalgus. One may frame the neurologic impairments as positive, *too much*, or negative, *too little*. Positive signs include excessive muscle tone and/or excessive movement. Negative signs include muscle weakness, deficiencies in selective motor control, and balance abnormalities.

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Fig. 40.1 (**a**) Ambulatory patient with spastic diplegia requires only a stick or pole for balance. (**b**) In contrast, a boy with spastic quadriplegia is barely able to crawl and requires complete support for activities of daily living. (**c**) Transportation is a challenge for many rural non-ambulatory patients, and the child in this example is carried in the traditional Nepalese *doko*

Spasticity is defined as a rate-dependent increase in muscle tone and is due to abnormalities in the pyramidal system that present as excessive stretch reflexes, resulting in a loss of motion at a joint (dynamic contracture). A fixed shortening of a muscle tendon unit is known as a myostatic contracture and also results in loss of motion. Dyskinetic CP involves hyperkinetic movements due to impairments in the extrapyramidal system (basal ganglia, thalamus). These include slow writhing movements of the fingers or uncontrolled movement of an entire limb. Patients with predominantly dyskinetic involvement rarely develop fixed musculoskeletal deformities. Often patients will have elements of both, with one type predominating.

Treatment Principles

Priorities for treatment include improving the patient's communication skills and activities of daily living and only later improving mobility. While a host of physical impairments may be identified, the disability will depend on the patient's environment, the extent of financial and emotional support from family and community, and cultural and religious perceptions. Traditional beliefs and the family's opinions influence the perceived causes of the condition, the treatment sought, and expectations. Realistic goals must be established, and all treatment should aim to improve function or participation in activities, rather than to correct specific impairments.

One of the most distressing aspects when asked to see such a child is the sense of impotence in the face of the family's hopes. However, the orthopedic surgeon has an important role, starting with a full, recorded history with a sympathetic and knowledgeable interpreter as a guide. A careful medical examination can identify underlying and associated functional conditions that might point to a treatable diagnosis. The musculoskeletal and neurological exams must be thorough, remembering that testing motor strength and passive range of motion are unreliable in the face of spasticity. In ambulators, the physical examination focuses on passive range of motion, degree of spasticity, muscle strength and selectivity, bony alignment, and observational gait analysis. In non-ambulators, the assessment focuses on passive range of motion, trunk balance, and spinal alignment.

An appropriate question is whether the patient will be able to walk with or without an assistive device if their orthopedic deformities are addressed. Assessment of the current level of function, the relative strength and motor control in the lower extremities, and the strength of their trunk and upper extremities will help answer this. Additional information includes the patient's cognitive/behavioral function, ability to participate in rehabilitation, and access to or willingness to use orthoses and/or assistive devices.

It often falls on the visitor's shoulders to explain to the family that some conditions have no cure and the problem is in the central nervous system, not the limbs. A delicate balance between realism and fatalism needs to be reached, requiring cultural sensitivity, best approached in tandem with a local counterpart. A community-based, family-centered strategy should be promoted. When family members are educated and encouraged to participate in the ongoing treatment, realistic goals can be set. In turn, trained family members can help influence and modify others' perceptions about the associated disabilities.

Surgical treatment should be individualized and is generally aimed at complications of spasticity such as contractures and deformities. The goals are to improve function. Orthotics is often an essential component of the treatment and should be available and acceptable to the patient and family. Counseling is essential to set goals, establish priorities, and instill appropriate expectations. While short muscles can be lengthened and rotational abnormalities corrected, abnormal tone and movements, muscle weakness and imbalance, and deficiencies in the selectivity of motor control will all persist.

Patients who require an assistive device for balance preoperatively will likely need one postoperatively (Fig. 40.2). While orthoses may improve biomechanical function, they are often poorly toler-

Fig. 40.2 A simple, low-cost bamboo walker

ated in cultures where shoes are not worn. When setting functional goals, the patient's current functional level can be assessed by the Gross Motor Functional Classification System (GMFCS), as follows:

1. Walks without limitations
2. Walks with limitations—cannot do long distance and has abnormal balance
3. Walks using a handheld mobility device
4. Self-mobility with limitations—support for sitting, needs wheelchair much of the time
5. No head/trunk control or self-mobility and requires a wheelchair

Contractures can be dynamic from spasticity or myostatic due to fixed shortening of musculotendinous units. Contractures are most common in the biarticular muscles such as the gastrocnemius, hamstrings, and iliopsoas. The moments generated across a joint are influenced by the force of the muscles crossing the joint and the skeletal levers across which they act. Coexisting bony rotational abnormalities and joint malalignment, termed "lever arm disease," may also impair biomechanical function (Fig. 40.3). Due to the complexity and progressive changes requiring ongoing need for treatment over the years, there is

Fig. 40.3 Ambulatory patients have a host of musculoskeletal problems in addition to their central nervous system impairment. (**a**) A patient with right-sided equinus, left equinovarus, bilateral knee and hip flexion with weight-bearing (spasticity, weakness, and/or contracture), internal rotation of left greater than right thigh, and patella alta. (**b**, **c**) These children walk with a flexed knee gait. Orthopedic interventions can improve function; however, patient selection is critical, and pathology at multiple levels must be addressed simultaneously

always a risk that even simple procedures will result in suboptimal outcomes. In general, surgery is best done by experienced practitioners and only when adequate rehabilitation is available.

Surgical Treatment

Surgery is most commonly considered in ambulatory patients (GMFCS 1-3) to preserve or improve function, recognizing that gait parameters may deteriorate into adulthood. Muscle weakness is common, and surgical lengthening will weaken the muscle further.

The proposed benefits of any procedure must be weighed against the possibility of untoward effects, as surgical procedures can result in loss of function, including the cessation of ambulation, especially when there is inadequate access to rehabilitation. Orthoses are often essential and must be acceptable to the patient and the family. Pitfalls in surgical treatment include failure to identify treatable abnormalities at other levels, overlengthening and in turn weakening muscle groups, failure to treat bony "lever arm" problems, and failure to have realistic goals and/or appreciate the contribution from abnormalities in muscle tone (spasticity, dyskinesia), muscle weakness, deficiencies in balance and proprioception, and the cognitive capacities and/or motivation of the patient and his or her family.

The most common muscles lengthened are the hamstrings and the gastrocsoleus, and techniques such as musculotendinous recession are preferred. A simple case example is that of equinus contracture at the ankle, which is commonly associated with contractures at the knee and/or hip. Equinus contracture is assessed by the Silfverskiold test, in which the foot is inverted to lock the subtalar joint and dorsiflexion assessed with the knee both flexed and extended. An isolated gastrocnemius contracture is identified when dorsiflexion is restricted with the knee in extension but normal when the knee is flexed. Isolated tendoachilles lengthening in patients with spastic diplegia carries a high risk of overcorrection, especially when the soleus is not contracted and when coexisting contractures are not simultaneously addressed. When performing a gastrocnemius recession or a lengthening of both the gastrocnemius and the soleus, it is best to aim to retain about 5° of dorsiflexion, as mild residual equinus is preferable to a calcaneus posture.

Correcting femoral or tibial torsional malalignment requires a derotational osteotomy, most commonly fixed with a plate (femur, tibia) or crossed Steinmann pins (tibia). For an equinovarus foot that is flexible, in the absence of a gait lab, lengthening both the gastrocsoleus and tibialis posterior along with a split tibialis anterior tendon transfer to the cuboid will often suffice, although additional procedures (soft tissue or bony) may be required to restore motion at the time of tendon transfer. The equino-planovalgus foot may benefit from a calcaneal osteotomy for lateral column lengthening in addition to gastrocsoleus recession, with or without a plantarflexion osteotomy of the medial cuneiform to restore forefoot alignment. Hindfoot arthrodesis is only considered for severe, fixed malalignment which cannot be corrected by osteotomy, especially in patients with limited ambulation (GMFCS 3).

The main clinical problems in patients with the greatest degree of neurologic impairment—spastic quadriplegia—are hip dysplasia with progressive subluxation and dislocation, scoliosis, and lower extremity contractures. Our impression is that these children do not usually survive in austere environments and often have medical comorbidities that increase the risk of anesthesia and postoperative complications. Surgical treatment is most often reserved for palliative muscle lengthening, for example, adductor or hamstring tenotomy, to improve positioning. For patients with a chronically subluxated or dislocated hip with arthritis changes, consider resection of the femoral head and neck with concomitant valgus osteotomy or subtrochanteric resection of the proximal femur.

Other Neuromuscular Conditions

Children with other neuromuscular diseases or syndromes such as Duchenne muscular dystrophy, spinal muscular atrophy, myopathies, arthrogryposis, and hereditary motor and sensory neuropathies such as Charcot-Marie-Tooth are often brought to a volunteer for evaluation. While it may not be possible to make a specific diagnosis based on history and physical examination alone, families should be counseled concerning the possibility of occurrence of a similar condition with future pregnancies. As with CP, treatments should be individualized and aimed at improving function.

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Part VII

Additional Considerations

41 Adult Reconstruction

Richard A. Gosselin, Harry E. Jergesen,
and Daniel-John Lavaly

Introduction

This chapter deals with the sequelae of adult orthopedic conditions, neglected injuries, failed treatments, and end-stage degenerative joint disease as they are dealt with by osteotomies, arthrodeses, and/or arthroplasties.

In all cases a thorough general medical and specific orthopedic history is necessary with particular attention to nutrition, tobacco use, and coexisting medical diseases. Identify the patient's specific complaint, perceived disability, and goals of treatment to avoid disappointment. The exam includes neurologic and musculoskeletal assessments and must be recorded. Patients must also understand the surgeon's goals.

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Reconstruction for Bone Healing Problems

Nonunions

Many patients present late after injury with an established malunion or nonunion. Pain, functional impairment, and anticipated premature joint deterioration are the indications for surgical management. Suboptimal cosmesis with near-normal function is not an indication for corrective osteotomy.

Nonunions are common, as most long bone fractures are treated non-operatively [1]. When infected, especially after one or more attempts at surgical treatment, they represent a formidable challenge. Hypertrophic nonunions are generally due to inadequate immobilization, and the fracture often responds to rigid external immobilization and compression loading or rigid internal fixation. Oligotrophic and atrophic nonunions are attributed to an inadequate biologic environment in which the body makes little or no attempt at callus, usually because of poor blood supply, poor nutritional status, or tobacco use. They usually require internal fixation and bone grafting (Fig. 41.1) (for bone grafting, see Appendix 3).

Humeral Shaft Nonunion

Humeral shaft fractures treated with hanging casts or coaptation splints (U-slabs) can lead to

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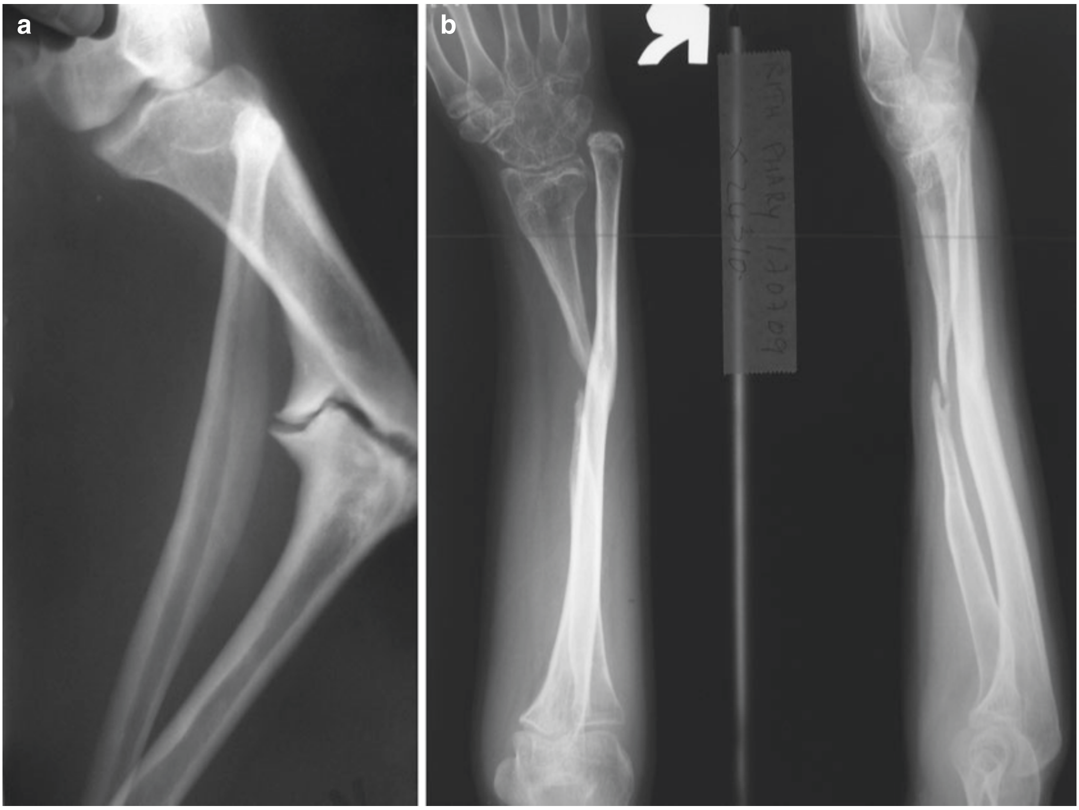

Fig. 41.1 (**a**) Hypertrophic mal-/nonunion of tibia. (**b**) An atrophic nonunion of radius with thinning and tapering of bone ends and no evidence of callus

nonunions, often of the oligotrophic type—particularly in the elderly and those with obese, flabby arms—or a true synovial pseudarthrosis, forming a “second shoulder” (Fig. 41.2).

These nonunions need rigid ORIF with a dynamic compression plate (DCP) or locked IM nail, usually with bone graft, and most commonly through an anterolateral approach, or if the radial nerve needs exploration, a posterior approach. Bone ends are resected to bleeding bone and the medullary canals opened. Shortening up to 3 cm is well tolerated. A second plate can be added in the face of osteoporosis.

Radial and Ulnar Nonunion

Non-operative management of both bone forearm fractures or inadequate surgical fixation with Steinmann pins or K-wires as “alignment rods” often leads to nonunion of one or both bones. No surgery is needed if one bone is healed, hand and elbow function are normal, and pro-supination is painless, but this is rarely the case. Rigid internal fixation of both bones with plates and screws, along with iliac crest bone graft that allows early mobilization, is the best option. Shortening up to 2 cm is acceptable, with both bones shortened the same amount. Re-establish the normal bow of the radius to maximize forearm pro-supination.

Nonunion of the distal radius and ulna is less common and, if symptomatic, should be taken down to bleeding viable bone and rigidly fixed (Fig. 41.3) with T plates or pinning and casting.

Scaphoid Nonunion

Scaphoid nonunions commonly present late with varying degrees of osteolysis, avascular necrosis,

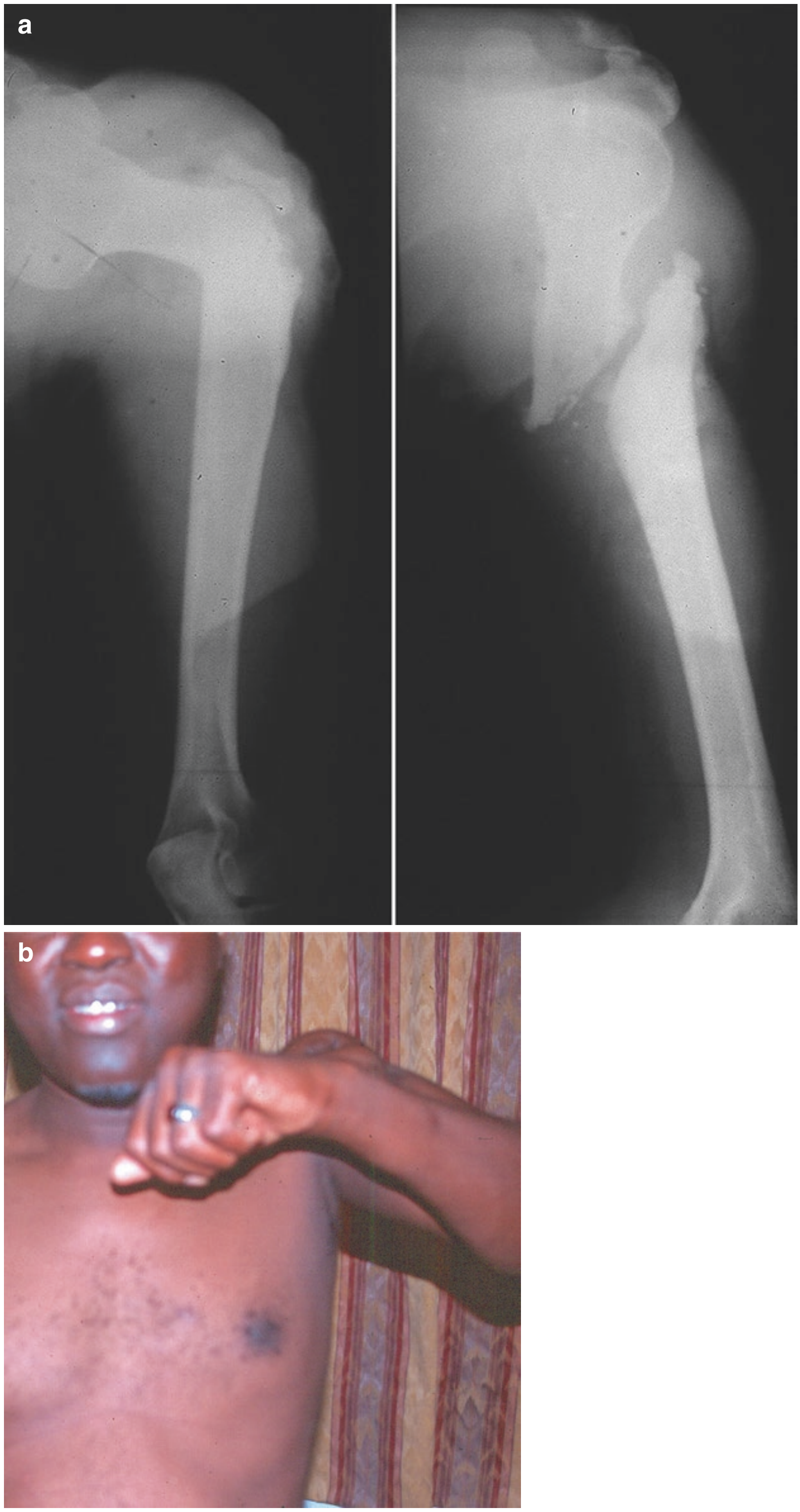

Fig. 41.2 (**a**) Hypertrophic pseudarthrosis of a proximal humerus fracture, (**b**) giving clinical appearance of "second shoulder"

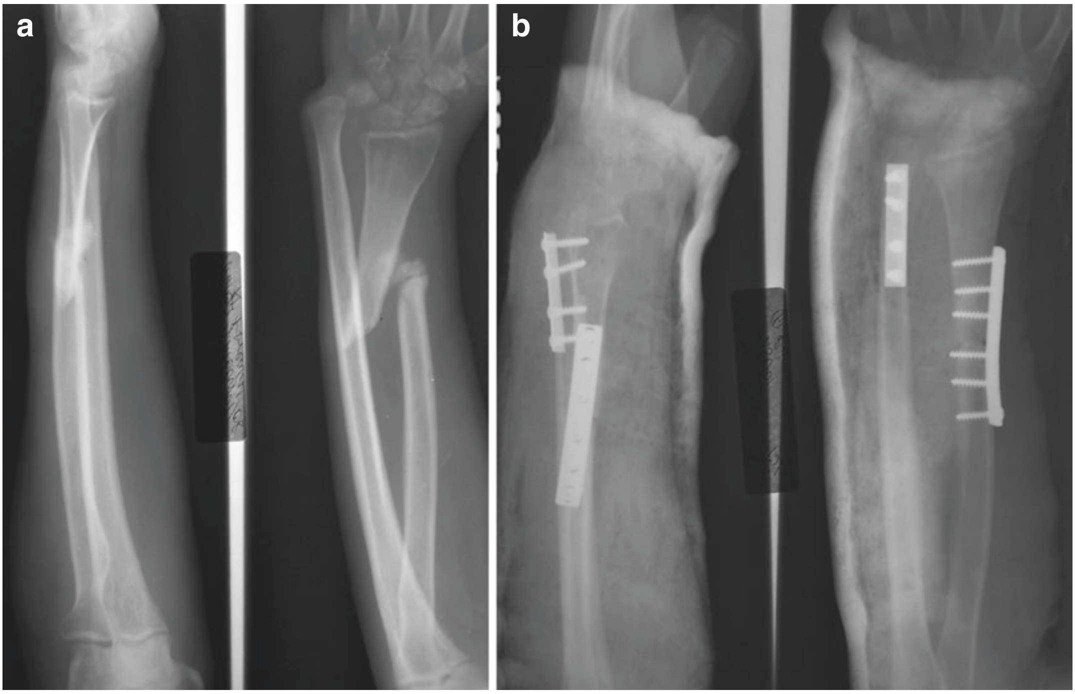

Fig. 41.3 (**a**) Oligotrophic nonunion of a Galeazzi fracture/dislocation. The bone ends are not tapered, but the attempt at callus is minimal. (**b**) Surgical treatment with internal fixation, bone grafting, and ulnar shortening. Note: the ulna is still 3–4 mm too long

collapse, or carpal instability. If the bone has retained its anatomic contours, the treatment is surgical. Through a volar or dorsal approach, the nonunion is curetted and packed with cancellous bone from the distal radius, olecranon, or iliac crest. Self-compressing screws are rarely available, but two parallel K-wires are effective. Pins are removed at 6–8 weeks, and thumb spica casting is continued for another 6–12 weeks.

Femoral Neck Nonunion

Established nonunions of femoral neck fractures are usually painful and disabling. A cementless hemiprosthesis is the best option. If fluoroscopy is available, percutaneous fixation with screws can be attempted in minimally displaced, relatively "fresh"—less than 3 months—fractures in younger individuals, but one should expect a high failure rate.

The only other option is an open reduction with or without internal fixation under direct vision or with fluoroscopy. The anterior approach is less likely to compromise the femoral head's vascular supply and should be used if only internal fixation is planned.

A posterior approach is needed if one plans to add a corticocancellous pedicle bone graft based on the quadratus femoris muscle (Judet or Meyers procedure) to the internal fixation [2]. In this procedure the femoral insertion of the quadratus femoris is exposed and osteotomized to include a segment of the intertrochanteric crest proximal to the quadratus insertion. The posterior hip capsule is T'ed open, the nonunion exposed, and fibrous tissue curetted from the nonunion site, creating a trough across the nonunion. The defect is filled with cancellous iliac bone chips, and the graft is rotated on its muscle pedicle to cover the defect. It can be secured with a single screw. Internal fixation of the femoral neck is achieved with two or three parallel, short-threaded 6.5 cancellous screws inserted in compression under direct vision from below the greater trochanter. The head can be temporarily pinned to the acetabulum with a Steinmann pin or drill bit, to avoid "spinning" during tapping or screwing. Six-week non-weight-bearing is followed by progressive weight-bearing as tolerated. This procedure is technically easier than it sounds, provides the added advantage of a vascularized graft, and is best reserved for younger patients. Although intuitively appealing, no long-term outcome data exist from resource-poor environments.

Another option is a 15–25° valgus osteotomy at or below the lesser trochanter, fixed in compression with a 135° blade plate, a DHS, or even a well-contoured large fragment DC plate (the straight plate can be bent through the fourth or fifth hole to become a blade plate). The procedure is much easier with fluoroscopy.

Femoral Shaft Nonunion

Nonunions with minimal or no shortening can be exposed by sharply elevating a cortico-periosteal flap anteriorly and laterally, disrupting as little as possible the linea aspera posteriorly (Judet's osteoperiosteal decortication). Excising all fibrous tissue, the two ends of the intramedullary canal are reopened and internally fixed with a statically locked IM nail (our preference), a dynamic nail with good three-point fixation (Fig. 41.4), or a compression plate (Fig. 41.5).

Bone grafting is mandatory for oligotrophic and atrophic nonunions with generous amounts of cancellous bone packed under the cortico-periosteal flap (Fig. 41.6). Hypertrophic nonunions most often heal with rigid fixation only, avoiding graft donor site morbidity.

Infected nonunions are appearing with increasing frequency after failed ORIF. The infection is addressed by a thorough debridement, removal of hardware if present and loose, along with sequestrectomy to remove all nonviable bone and avascular segments. Hardware that is solid and still contributing to stability can be retained, until there is enough bone healing to allow it to be safely removed. Every effort should be made to mechanically remove as much of the biofilm as possible. Antibiotic beads or spacers can be made with 1.2 g of tobramycin, 2 g of vancomycin, or 6–80 ml vials of gentamicin per batch of cement (any heat-stable antibiotic singly or in combination can be used). Dead space closure and bone coverage with healthy thigh muscle are usually possible.

Another option is temporary stabilization with an external fixator, while the wound is left open to granulate from within. The wound is reassessed at 6 weeks, and if clean, the nonunion site is bone grafted and internally fixed. Suspicious fixator pin tracts should be curetted, the patient put at bed rest, possibly in traction for 7–10 days, and treated with antibiotics before internal fixation.

Chronically infected femoral nonunions represent a formidable challenge. They occur most commonly after an open road or ballistic injury, often after one or more failed attempts at fixation and almost always associated with damage to the surrounding soft tissues. CT or MR imaging and a reliable microbiology lab are useful for diagnosis and treatment planning, but rarely available. Most often the diagnosis relies on history, clinical examination, and plain X-rays. The treatment has two goals: eradication of the infection and consolidation of the nonunion, in that order (see Chap. 31, Chronic Osteomyelitis in Children—the same principles apply).

The first goal is achieved with a wide excision of the infected segment through non-infected tissues and bone, similar to oncologic resection. This is not always easy to determine. The cuts should be through bleeding bone, thus with the tourniquet deflated (beware: blood loss can be significant. Do not attempt without a blood bank). The remaining bone can be managed in one of two ways: external fixation and bone transport [3] or internal fixation and the induced membrane technique of Masquelet [4] (https://www.youtube.com/watch?v=cYc2peeotAM).

Treating long bone infections by either of these techniques is time consuming and can take many months to conclude treatment. Appropriate orthopedic monitoring by a qualified surgeon is mandatory throughout the process; otherwise it should not be started. The authors have no experience with bone transport for this indication, and thus only the induced membrane technique will be described.

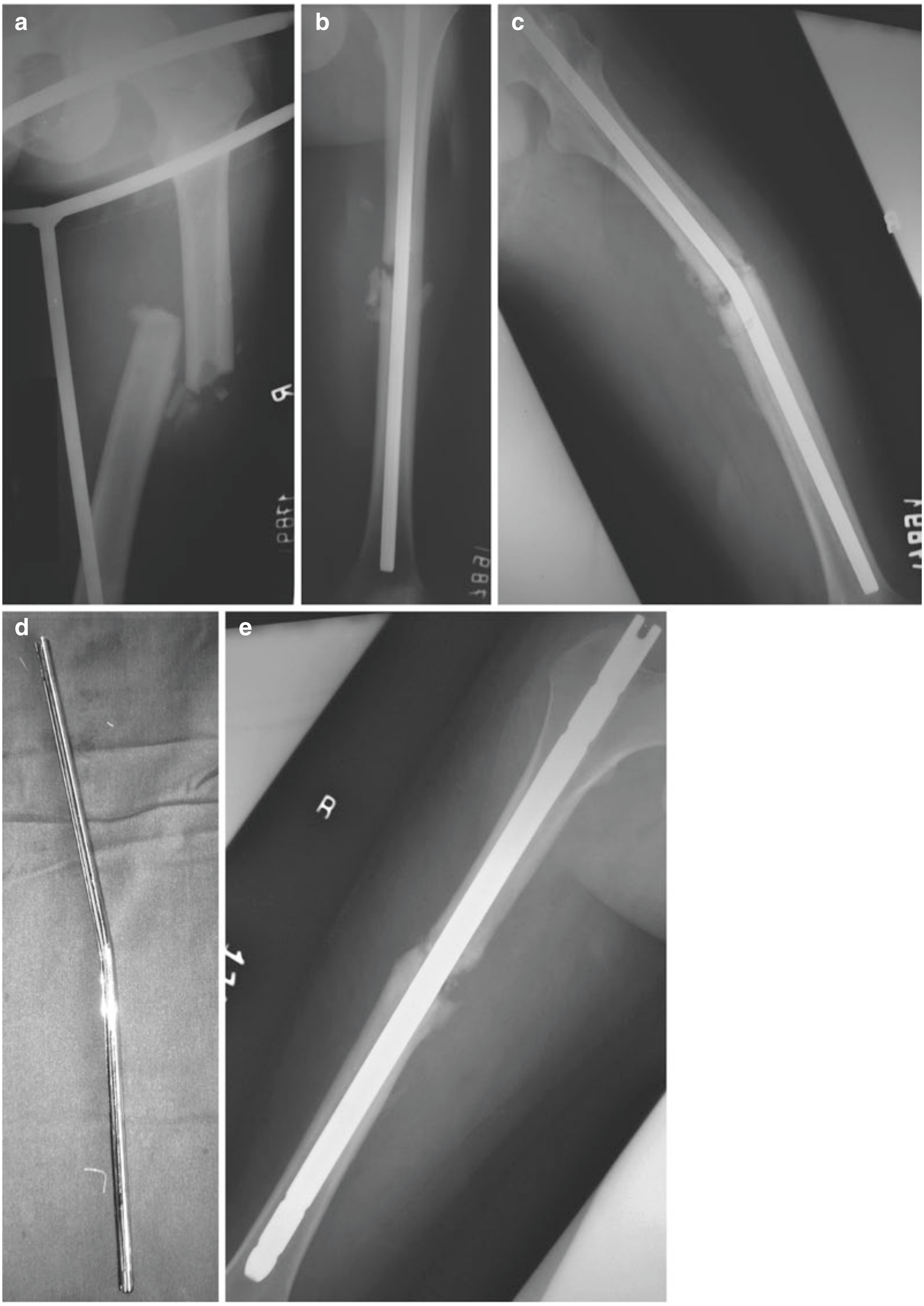

Fig. 41.4 (**a**) Comminuted transverse fracture of right femoral shaft. (**b**) ORIF with Kuntscher nail. (**c**) Nonunion at 6 months with the nail bent, but not yet broken. (**d**) The surgeon was lucky that the nail came out easily. (**e**) A bigger nail was inserted without opening the nonunion, hoping that the reamings alone would provide sufficient bone graft and progressive weight-bearing would encourage union. The nail was not interlocked because there was no fluoroscopy and the proximal jig was broken

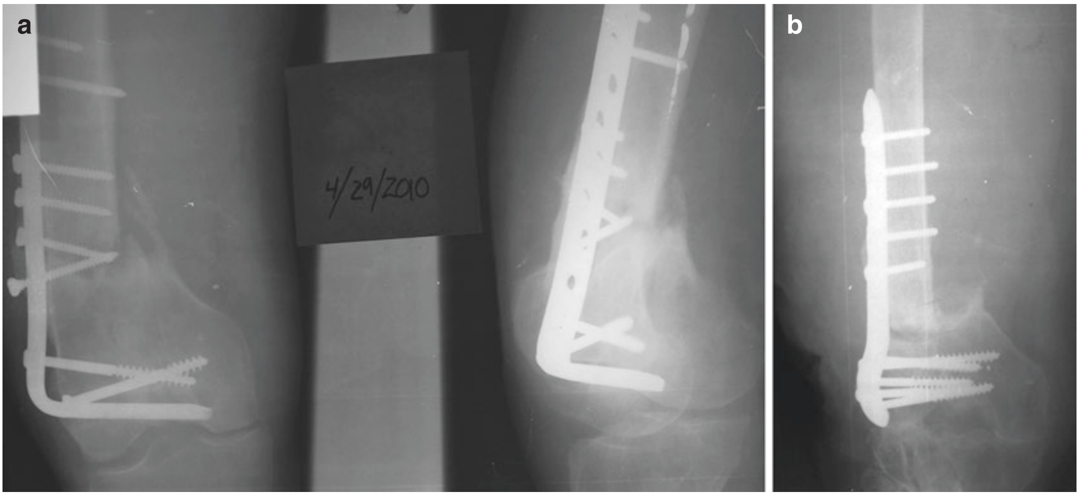

Fig. 41.5 (**a**) Nonunion of distal femur fracture with blade plate failure. (**b**) After debridement and shortening, the femur was fixed in compression, with medialization of the distal fragment, in a slightly varus position

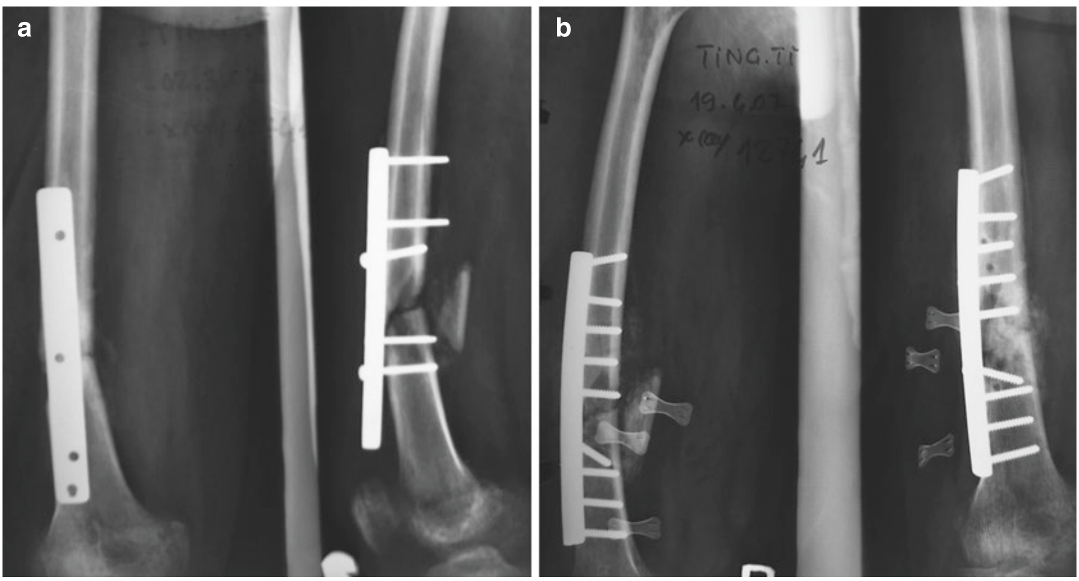

Fig. 41.6 (**a**) Delayed union 4 months after ORIF of a distal femoral shaft fracture. Unsatisfactory fixation has led to hardware failure. (**b**) Treated with replating and ample bone graft

Induced Membrane Technique

If using external fixation to stabilize the bone during the first stage, it is prudent to apply it, at least partially, before bone resection, to maintain length. The size of the resection in this first stage is determined as above by clinical signs unless one has access to advanced imaging or a reliable lab and is limited only by the amount of bone graft available for the second stage. Although it is often cited that results are progressively less dependable with resections greater than 5 cm, we have seen successful unions with up to 20 cm resection. Be aware of available graft limitations from previous graft harvesting or significant osteoporosis. The bone defect is filled with a cylinder of cement of equal diameter, capping the exposed bone ends for 1–2 cm. Although Masquelet himself does not incorporate antibiotics in the cement, we still use a combination of vancomycin and tobramycin or gentamicin and have not seen untoward effects.

Other than ex fix or traction after resection of the diseased bone, a cement nail can be used to stabilize the bone without the potential pin tract problems of external fixation (see Box 41.1).

The spacer is left 6–8 weeks, during which time a biologically active membrane forms. Ten to fourteen days before proposed spacer removal and bone graft, remove the ex fix and curettage the pin sites. If microbiology is available, bone specimens from the tip of each stump and pin site curettings should be cultured. Immobilize the extremity with a splint, cast, skeletal traction, or new, temporary ex fix. If the cultures are positive, stage 1 must be repeated in full with a thorough debridement a new spacer and immobilization. If the cultures are negative, the second stage consists of sharply and carefully opening the membrane; removing the spacer, or the spacer and cement nail; and gently inserting the definitive internal fixation (we prefer a nail to a plate) paying particular attention to not damaging the membrane. The gap is filled with bone graft, usually autogenous (see Appendix 3). The wound is closed, and a thick fluffy dressing is applied as drainage is expected for the first 2–3 days.

In the best-case scenario, sequential X-rays will show progressive consolidation, without clinical evidence of wound healing problems or recurrence of the infection. Minor and major complications are common, and the patient needs to know from the onset that amputation may be the final outcome. Most patients will say they understand and agree, but when the surgeon says that amputation is the only remaining option, many patients will not consent. This, a particularly troublesome problem when the patient is between stages, still has a spacer and an ex fix that will sooner or later fail (Figs. 41.7 and 41.8).

The induced membrane technique also has a place in acute, non-infected situations of bone loss greater than 5 cm. The same principles apply of staged preparation of an osteoinductive bed by means of a cement spacer, often over a locked IM nail. In such cases, we usually use antibiotics in the cement because of the extent of associated soft tissue damage. We usually prepare both anterior pelvises for bone graft harvest and have on occasion taken from all four pelvic sites.

Box 41.1 Making a Cement Nail

Thread a long stout wire or Ilizarov rod down a 36 Fr or 40 Fr chest drain, leaving enough metal exposed for easy extraction. Fill chest drain with very liquid antibiotic impregnated cement. Cut the chest drain and peel from the hardened cement nail.

Before inserting the nail, wrap it with sterile aluminum foil, and prepare the cement spacer on a back table, either freehand or molded in a pre-measured length of a 60 cc syringe. While still doughy, cut the prepared spacer into two hemi-cylinders, and shape the two halves over the foil-covered nail until hard, creating two easily separable hemi-cylinders of cement that fill the resected gap.

The femur is reamed thoroughly, the cement nail is inserted, and the bone gap is filled with the two hemi-cylinder spacers, held together by heavy non-resorbable sutures.

Nonunion of Fractures About the Knee

Displaced fractures of the distal femur, proximal tibia, or patella lead to premature degenerative joint disease if not adequately reduced and securely held. They are commonly associated with ligamentous injuries, compounding the problem. The decision to intervene surgically is based on the age and condition of the patient,

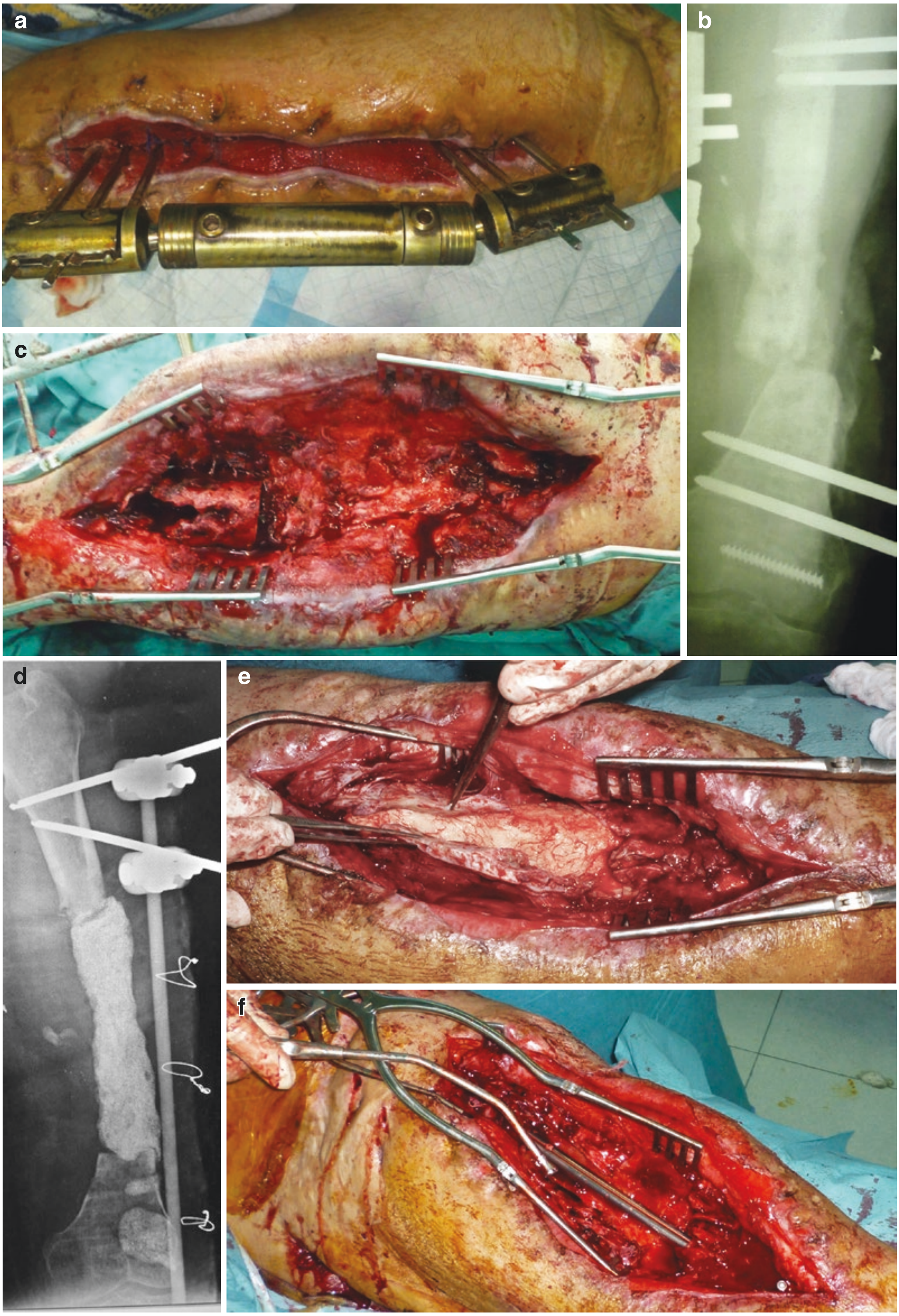

Fig. 41.7 (**a**, **b**) Appearance of thigh and X-ray on admission. (**c**) Stage 1 intra-op photo, after removing 19 cm of infected bone. (**d**) Post-op X-ray showing cement spacer with tobramycin and vancomycin and knee-spanning ex fix. (**e**) Second stage at 8 weeks, the induced membrane is thick. Cement is carefully removed after sharply incising the membrane. (**f**) The nail placed. All four iliac crests were used to fill the defect

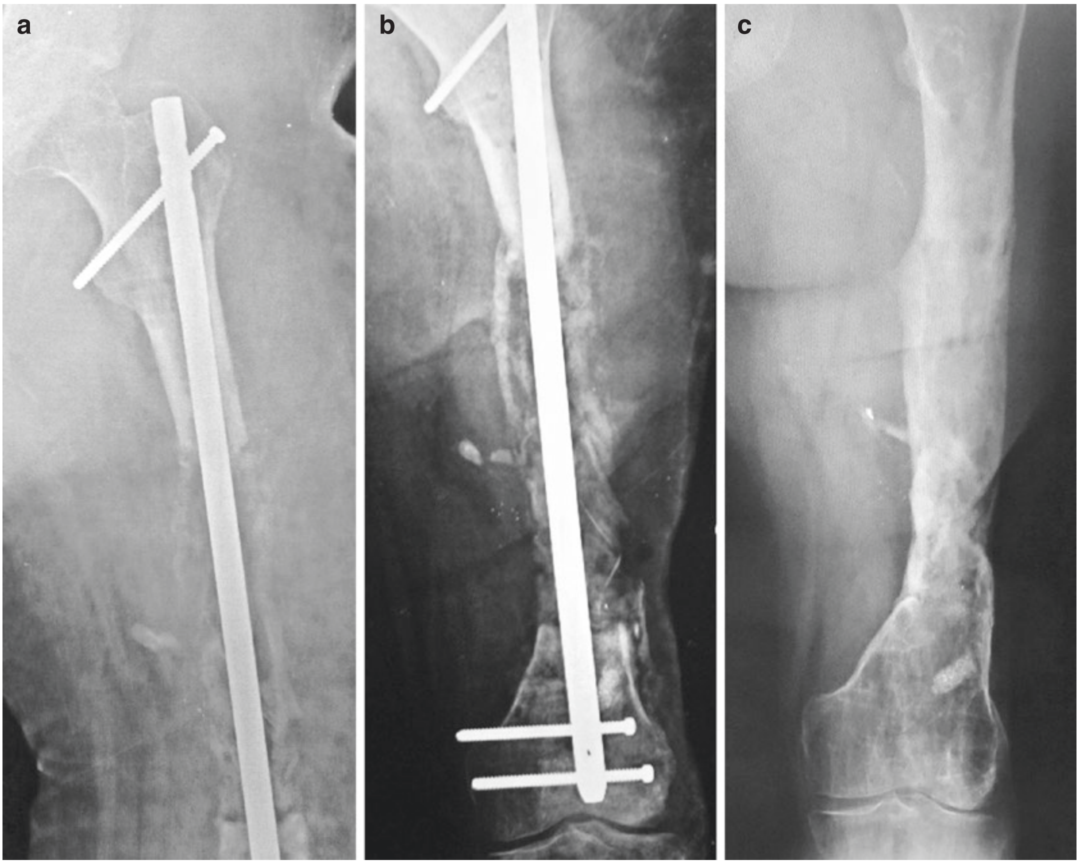

Fig. 41.8 (**a**) Post-op X-ray of locked femoral nail and bone graft. (**b**) X-ray 4 months later showing progressive maturation of the graft; (**c**) femur healed 19 months after stage 1 procedure. Patient has full painless weight-bearing without drainage. He is 3 cm short but refuses to use lift

activity level, time since injury, degree of comminution, amount of displacement, safety of the surgical environment, implant availability, and, importantly, the surgeon's experience. Older fractures with already existing signs of degenerative arthritis are best left alone until symptoms are severe enough to warrant joint replacement or fusion.

Nonunion of the femoral condyles or tibial plateau is usually painful with weight-bearing. A single large, undisplaced fragment can be fixed in situ with compression screws. With displacement greater than 2 mm, the fragment should be mobilized, reduced, and fixed, with supporting bone graft if needed, but only if the fragments can be reduced and fixed anatomically. A neutralization plate can improve the rigidity and allow early motion. Weight-bearing is avoided for at least 6 weeks.

Meniscal lesions should be properly addressed. Ligamentous reconstruction beyond simple repair has a high risk of failure due to stiffness. Unless the secondary stabilizers—quadriceps and hamstrings—are also significantly damaged, most patients will develop satisfactory compensatory mechanisms with directed therapy.

Nonunion of the patella is addressed only if symptomatic. Occasionally a displaced, noncomminuted transverse fracture nonunion will benefit from mobilization, reduction, and fixation with tension banding or compression screws. Small, comminuted polar fragments can be excised and the patellar or quadriceps tendon reattached with heavy non-resorbable transosseous sutures. Some degree of residual stiffness and/or weakness will remain. Patellectomy may be the only solution to manage disabling pain, but weakness with running and stair climbing and an extension lag is almost unavoidable despite meticulous soft tissue reconstruction.

Nonunion of Tibia/Fibula Shaft Fractures

Nonunions that are not infected are approached in the same way as those in the femur (Fig. 41.9). With stable internal fixation with an IM nail, immediate weight-bearing is encouraged, even if only partial. Some surgeons routinely perform a fibular osteotomy (our preference), but this is not univer-

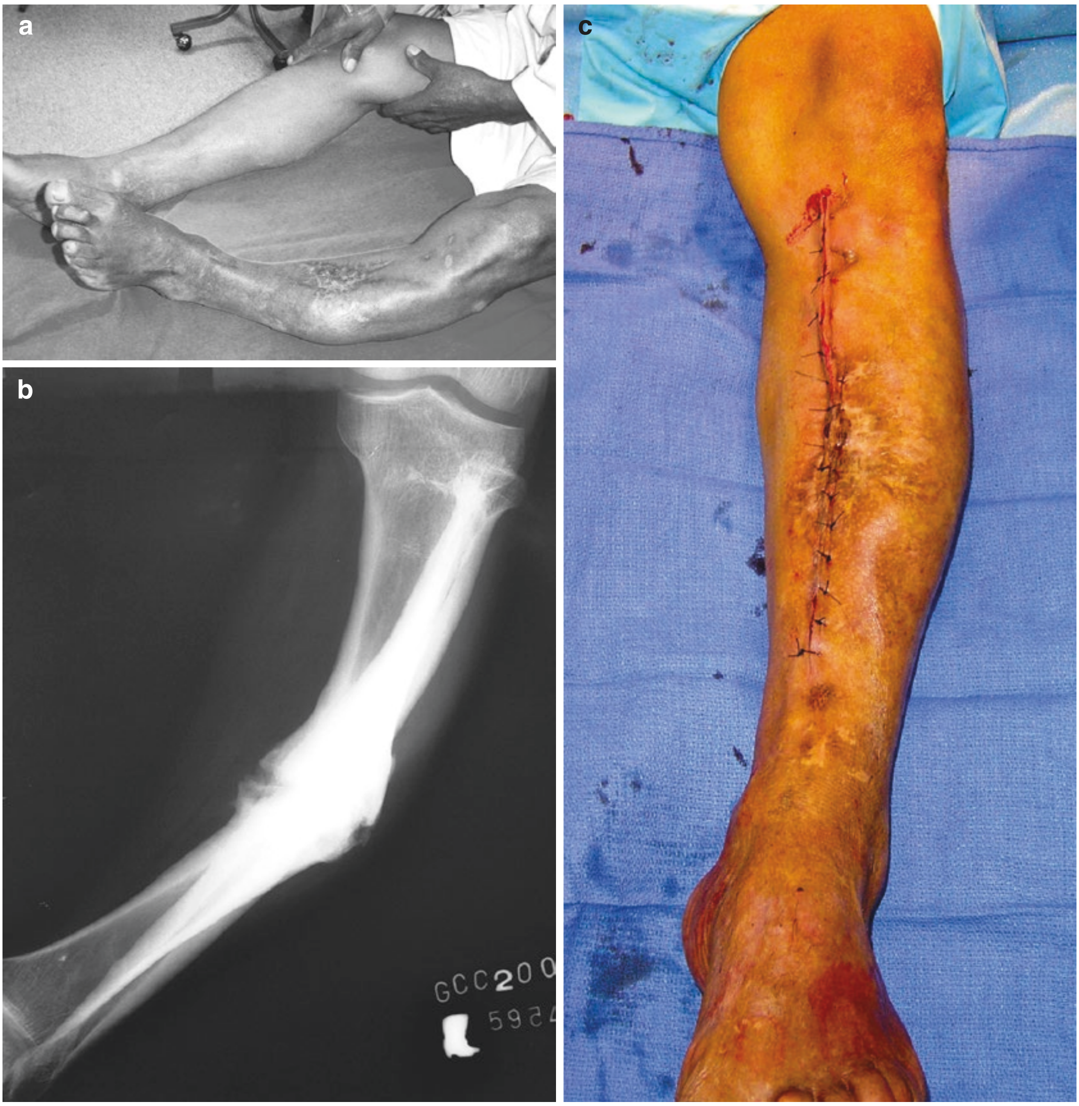

Fig. 41.9 (**a**, **b**) Clinical and radiographic appearance of a 55-year-old male with a hypertrophic nonunion of a 16-month-old mid-shaft tibia fracture. (**c**–**e**) Clinical and radiographic appearance after segmental resection of fibula, nonunion takedown, bone graft, and statically locked IM nailing

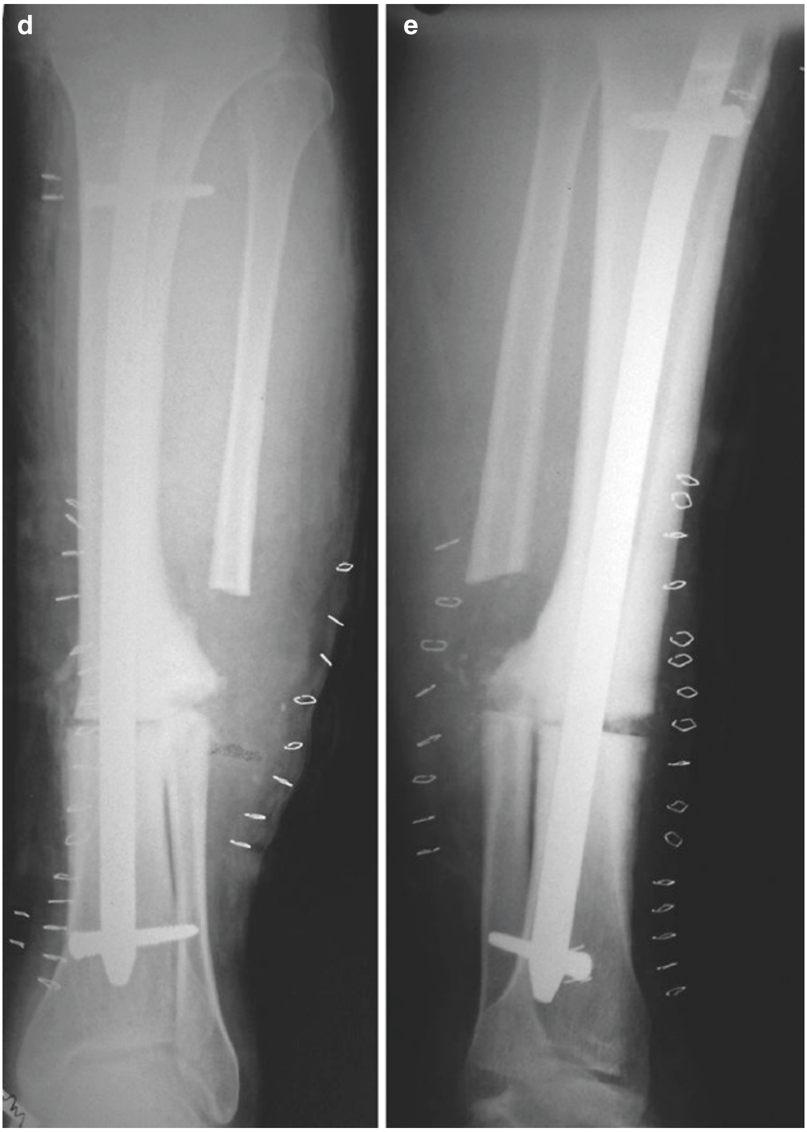

Fig. 41.9 (continued)

sally accepted (Fig. 41.10). Oligotrophic and atrophic nonunions are bone grafted. Shortening of both segments should not exceed 1–1.5 cm. For nonunions near the ankle, a posterolateral approach is preferred to preserve the local blood supply.

Infected Tibial Nonunions

In resource-poor environments, management of an infected tibial nonunion commonly involves multiple surgical procedures over a long period of time. The many constraints of this approach should be carefully weighed, and the patient made aware of the prolonged and costly process. The first objective in treating an infected, ununited tibial fracture is to control the infection (see Chap. 31, Chronic Osteomyelitis in Children—the same principles apply).

To address instability after debridement of infected bone, the main fragments should be stabilized with an external fixator, a bivalved or windowed cast, or traction through the distal tibia or calcaneus. A saucerized bone that retains two-thirds of its circumference does not need to be stabilized if the patient is compliant with non-weight-bearing. Depending on the available resources and expertise, the wound can be managed open or closed.

Closed management after debridement is with bone graft and wound closure. If bone loss is greater than 3–5 cm, we suggest the induced membrane technique of Masquelet as described above. Though surgical wounds after debridement on the femur in stage 1 can often be closed primarily, the problem in the tibia is soft tissue coverage on these often multi-operated legs, particularly over the distal half. The surgeon needs knowledge of basic flaps: fasciocutaneous, gastrocnemius, soleus, perforator, and cross-leg flap. A healed flap can safely be elevated in its entirety at 6–8 weeks to proceed to stage 2. The medial gastrocnemius works well for nonunions in the proximal third of the tibia and the soleus for the middle third. Wounds needing a soleus flap are often caused by high-energy trauma, with devitalization of the soleus, making this generally less reliable than a gastrocnemius muscle flap. Distal third tibial nonunions remain a problem, as free flaps are rarely available. Fasciocutaneous flaps provide soft tissue coverage throughout the tibia except around the ankle. They do not bring in as robust a blood supply as a transposed muscle, but are easier for the less experienced surgeon. Cross-leg flaps in patients under 25–30 years, reverse sural artery flaps, perforator flaps, and other local flaps are options for those experienced (see Chap. 14).

Fig. 41.10 Natural history of tibial fracture nonunion: (**a**) initial X-rays shortly after injury involving both tibia and fibula. (**b**) Appearance after closed reduction and molding in AK POP. (**c**–**e**) Progressive varus angulation and hypertrophic nonunion over 6 months. (**f**) Treatment with ORIF with interlocked IM nail, fibular osteoclasis at malunion site, and local bone graft. (**g**) Appearance 6 weeks later when patient was full weight-bearing without pain

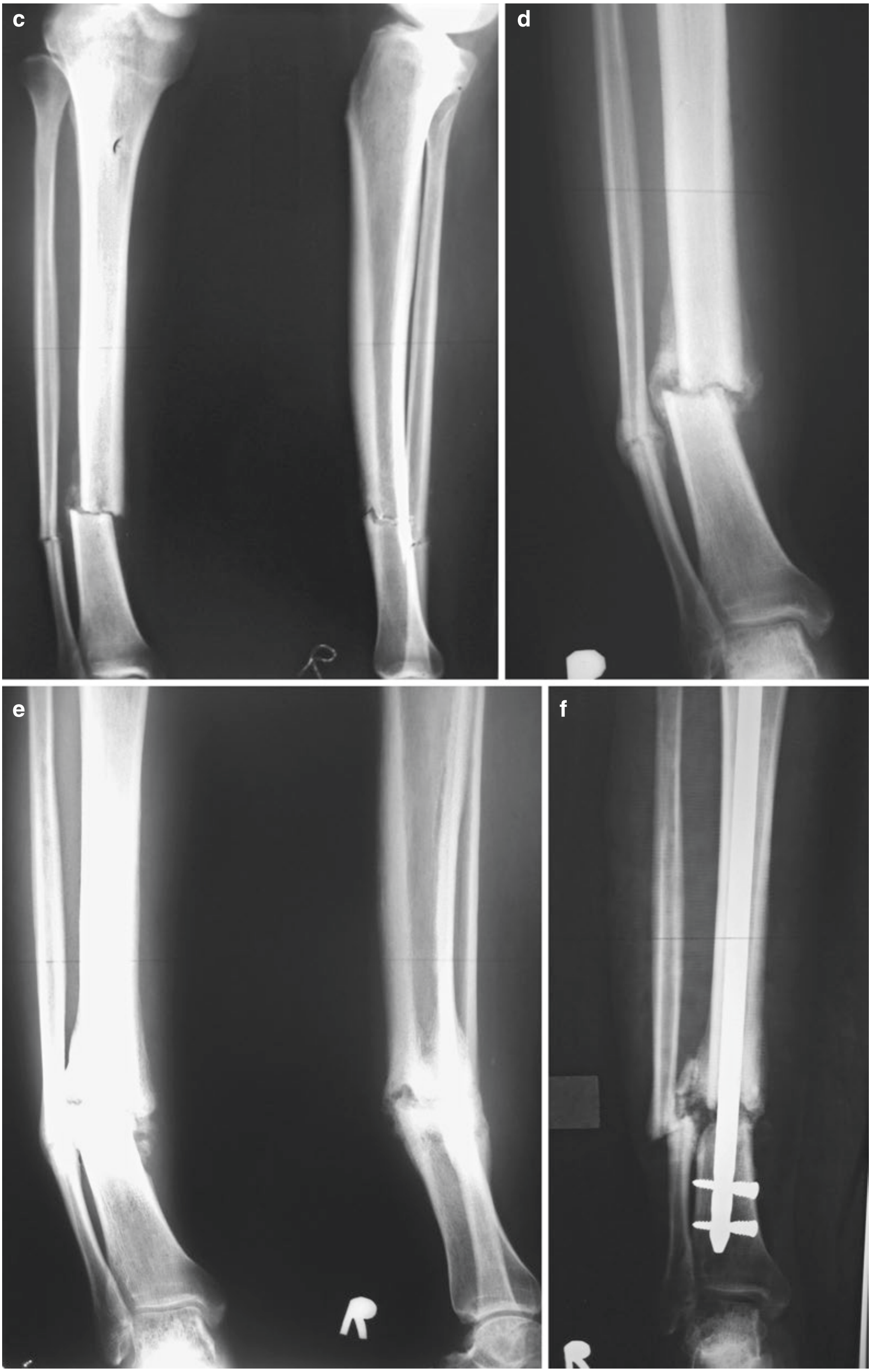

Fig. 49.10 (continued)

Fig. 49.10 (continued)

The open technique of bone grafting as described by Papineau [5] (Box 41.2) is primarily used in tibial bone loss or nonunion. He believed that the mechanical action of direct irrigation in the show promoted healthy granulation tissue and saw no difference in infection rates when comparing clean but non-sterile shower water with sterile saline for irrigation. When the skin and underlying soft tissues are healed and X-rays demonstrate sufficient bone consolidation, usually 4–8 weeks after skin grafting, the fixator is replaced with an above-knee or patellar tendon-bearing cast. Progressive, protected weight-bearing continues until clinical and radiographic consolidation is present. A fibular osteotomy is considered if there is varus drift or no progress to consolidation after 3 months. In open wound

Box 41.2 Papineau Technique

- Thorough debridement and, if unstable, >1/3 diameter of bone missing, apply ex fix.
- Wound left open and mechanically irrigated daily in shower before dressing change.
- When healthy granulation covers wound bed, pack the cavity with generous cancellous bone chips.
- First post-op dressing in 4–5 days (likely a few chips will come with dressing).
- Daily gentle irrigation with sterile NS or water until granulation tissue comes up through graft.
- Resume daily shower mechanical irrigation.
- STSG when granulation covers the bone graft.

techniques, local negative pressure systems, honey, sugar, or papaya paste have been described, with varying degrees of success.

Another approach to managing infected tibial fractures in the pediatric or young adult population is to bypass the infected region by a tibiofibular synostosis proximal and distal to it (Fig. 41.11). This procedure is done through a posterolateral (Harmon) approach with the patient in a lateral or prone position, giving access to the posterior iliac crest where bone graft is harvested. This approach is useful when extensive anterior tibial soft tissue debridement is necessary to address the infection, when a large bone defect is present, and/or when bone transport is not available. After the grafting, a non-weight-bearing above-knee cast is applied and replaced at 6–8 weeks with a weight-bearing AK cast, a patellar tendon-bearing cast, or brace that allows the intact fibula and adjacent bone graft to hypertrophy over the course of 12–24 months until full weight-bearing commences.

Nonunion of Fractures About the Ankle

Intra-articular fractures of the distal tibia, or malleolar fractures, are common and often present

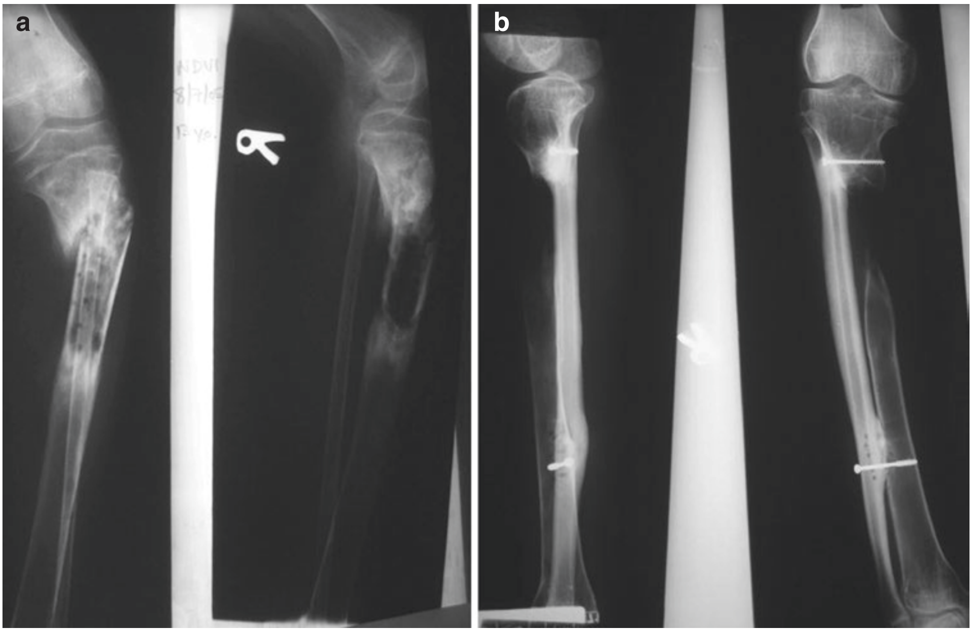

Fig. 41.11 (**a**) Infected nonunion of proximal tibia pathologic fracture secondary to chronic osteomyelitis. (**b**) Two years after debridement and tibiofibular synostosis without osteotomizing the fibula. The fibula is visibly hypertrophied without signs of recurrent infection

late (Fig. 41.12). Patients assume the injury was a “bad sprain” and resume weight-bearing as pain allows or are treated by a local healer and inadequately immobilized. In both scenarios, premature weight-bearing tends to displace the fracture in the direction of the initial injury, most commonly in pronation and external rotation.

The goal of treatment is to reposition the talar body anatomically under the distal tibia, before secondary degenerative changes commence. Because residual displacement dramatically alters the area of contact in the tibiotalar joint, degenerative changes can occur rapidly, making a short window of opportunity for effective treatment. The absence of pain usually means that the young fracture has consolidated, but if pain is present, it is often difficult to determine if it is due to residual motion at the fracture site or synovitis from early articular cartilage wear. Any suspicion that there is motion at the fracture sites can be confirmed with fluoroscopy, stress X-rays, or differential anesthetic blocks.

Some malleolar and pilon fractures that are less than 8–10 weeks should be treated with open reduction and internal fixation (Fig. 41.13).

Fig. 41.12 Natural history of neglected displaced intra-articular ankle fracture, with impressive grooving of the talus. At this stage, arthrodesis is the only surgical option

Fig. 41.13 (**a**) Displaced bimalleolar fracture/subluxation at 12 weeks. (**b**) Note the presence of callus laterally, but little medially. (**c**) The fracture was taken down and internally fixed with plate, screw, and pin, with an acceptable X-ray. The joint line is already narrowed with anterior beaking, and this patient may still need an arthrodesis

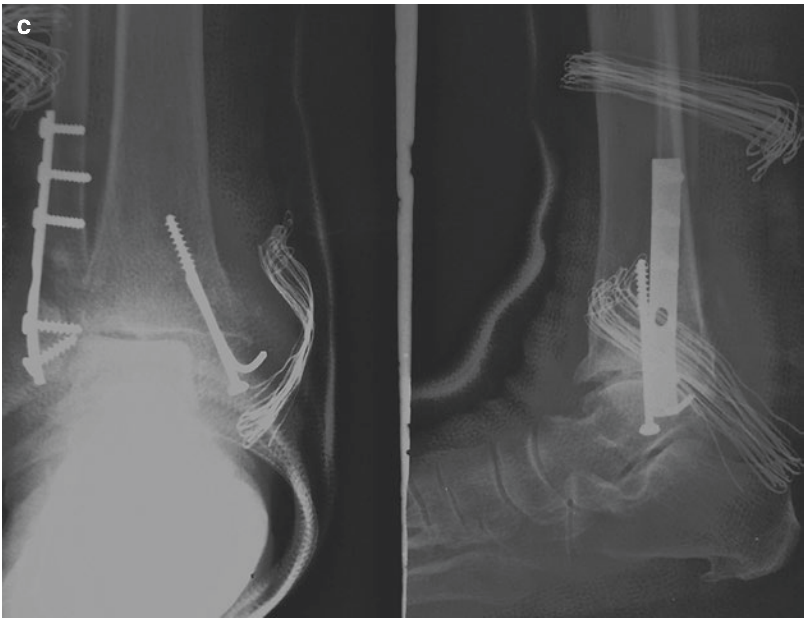

Fig. 41.13 (continued)

Pilon fractures that are simple, with one large fragment involving more than one-third of the articular surface, displaced more than 2 mm, and have no evidence of advanced consolidation on X-rays can be fixed with compression screws and/or plates. All other late pilon fractures are best handled non-operatively, with treatment focused on functional rehabilitation and surgery most likely a fusion.

Symptomatic undisplaced malleolar nonunions can be treated with compression fixation in situ by screws or plates. Displaced nonunions should be mobilized, reduced, and fixed so the talus sits as anatomically as possible under the distal tibia. In bimalleolar injuries, both malleoli must be mobilized and fixed to achieve this goal. Postoperative deforming forces can be temporarily neutralized by a sturdy Steinmann pin drilled from the calcaneus through the talus and into the distal tibia. The pin is left protruding at the plantar aspect of the heel and protected with a non-weight-bearing below-knee cast and removed after 6–8 weeks. Such pins should be used only in patients who can understand and comply with the non-weight-bearing status.

Malunions

Malunion of Humeral, Radial, or Ulnar Shafts

These rarely translate into a significant functional impediment in the humerus, though it will limit pro-supination when in the forearm. For angular deformities, a closing wedge osteotomy at the apex of the malunion and internal fixation with or without grafting may be indicated. Rotatory malunions are more difficult to precisely assess and treat but usually create more of a cosmetic problem than a functional one.

Malunions of intra- or extra-articular fractures of the distal radius are more common. Shortening, radial deviation, and volar apex angulation, after a Colles fracture, are the most common presenting deformities and usually associated with a dorsally prominent, occasionally dislocated distal ulna. If there is a displaced intra-articular component, early degenerative changes with pain and stiffness can occur. The same is true for the rarer volarly prominent Smith fracture.

For those with complaints of pain or disability, restoration of a more anatomic alignment can improve both function and cosmesis; however, it is often surprising how patients, particularly in the older age group, have much better clinical function than X-rays suggest.

The typical Colles deformity is approached dorsally, by a dorsal-radially based opening wedge osteotomy to restore the 10–15° of volar tilt and improve length and radial inclination. It is important to preserve a volar cortico-periosteal hinge at the apex of the osteotomy to prevent distraction and/or translation when the wedge is opened. A corticocancellous bone wedge from the iliac crest is press-fit into the opened osteotomy with cancellous chips filling the remaining gap. Internal fixation with a small plate is preferred, but bicortical pinning with K-wires is also effective. A below-elbow cast is worn for 6 weeks, after which the pins are removed and a new cast applied for 6 more weeks. The deformity associated with a malunited Smith fracture is approached volarly, with a similar opening wedge technique.

If residual positive ulnar variance remains unacceptable—5 mm or more—or the ulnar styloid is too prominent, an ulnar shortening held with a small tubular plate, lag screws, or K-wire (preferred) should be carried out. Excision of the distal ulna (Darrach procedure) should be avoided as the long-term functional outcome is not very satisfactory.

Intra-articular malunions are technically more challenging, but sizeable single fragments can be mobilized, reduced, and pinned, using cancellous bone for support. This should be done before the corrective opening wedge is created.

Malunion of the Proximal Femur and Shaft

Osteotomy for malunion should be considered if the mechanical axis deviates by more than 10° in the frontal plane and 15° in the sagittal plane. Malrotation is more difficult to assess, but more than 15–20° of a rotational difference compared to the opposite side should probably be corrected. Deformities are usually multi-planar, requiring a comprehensive physical exam with a detailed understanding of the problem for surgical planning (Fig. 41.14).

Femoral shortening less than 2 cm can be managed with a shoe lift. Up to 5 cm can be corrected with a single surgery, especially if a femoral distractor is available. Lengthening of more than 5 cm should not be attempted as a stretch injury to the sciatic nerve, or a thrombosis of the vasculature can result in a complication much worse than a leg length discrepancy.

If shortening is due to healed overriding bone fragments giving the malunion and end-to-end reduction is not possible, the femur should be shortened and the residual length discrepancy addressed with a shoe lift. If regaining length is necessary, an alternative, after release, is distal femoral skeletal traction with 10 kg for 2–3 weeks, followed by delayed internal fixation. The surgeon should weigh the increased risks of infection and bleeding using this two-procedure technique. Proximal tibial traction might lessen the potential for infection caused with a distal femoral pin, but the traction weights across the knee ligaments can also cause injury. A third and safer option is slow and progressive correction and lengthening with osteoclasis and a distraction frame, as with the Ilizarov method, with the caveat that these should not be attempted by inexperienced surgeons and/or when no experienced surgeons will be present to handle the complications.

When the femoral length discrepancy and malunion can be handled at one sitting, it is approached laterally, and the fragments osteotomized and mobilized to regain the anticipated length. Angular malunions are addressed with the removal of appropriate bone wedges. The ends of the fragments are "refreshed" with a Gigli saw or rongeur, and the canal opened on both sides. Palpating the linea aspera helps preserve proper rotational alignment. "Marking" the cortex with a saw or the electrocautery on each side of the proposed osteotomy is helpful in maintaining the rotational alignment. A statically interlocked IM nail (our preference) or a large DCP, preferably with eight cortices on

Fig. 41.14 (**a**) X-ray of a 36-year-old male with bilateral fibrous ankylosis of the hips, which the patient said was due to a football injury in his early teens. He had no pain and no motion. (**b**, **c**) Standing and sitting appearance of the patient, demonstrating severe adduction/extension/external rotation of the right lower limb, with compensatory recurvatum of the knee. (**d**) As arthroplasty was not an option, the patient underwent a flexion/abduction/derotation osteotomy, fixed with a DHS and a DC plate. (**e**) Clinical appearance the day following surgery. (**f**) X-ray taken the following year showing a healed osteotomy. The patient underwent a total hip replacement of the left hip at this time. He was doing well the third year and declined to have his osteotomy side converted to a total hip

Fig. 41.14 (continued)

each side, can rigidly hold the osteotomy. Bone grafting is usually not required, but any excised bone can be used as local graft. When there is no shortening, an elegant alternative to correcting multi-planar malunions with multiple complicated wedges is the "clamshell" osteotomy [6, 7]. The femur is osteotomized through healthy bone just above and just below the malunion, creating a malunion "segment." This intermediate fragment is pre-drilled and bivalved with an osteotome from front to back, keeping intact as much soft tissue attachment as possible, especially posteriorly. A statically locked IM nail lies between the bivalved bone fragments, as in a segmental fracture (Fig. 41.15). The shorter the segment, the closer it is to the midshaft, and the more normal the anatomy of the proximal and distal canals, the greater the likelihood that the nail will yield correction in all planes. Correction of malunited fractures at the metaphyseal junction with this technique is less predictable, particularly in rotation, and sound clinical judgment is necessary before attempting such surgery.

Fig. 41.15 (**a**) This 45-year-old male's IIIA open femur fracture from a gunshot was debrided and placed in an ex fix in 10° varus. (**b**) After removal of the ex fix and unprotected weight-bearing, the varus increased to 20°. (**c**) X-ray after clamshell osteotomy secured with a locked retrograde nail. No extra bone graft was used. (**d**) AP and lateral X-rays taken 2 years after the osteotomy show and patient's femur healed without deformity or shortening, and he walks with a normal gait and full squat

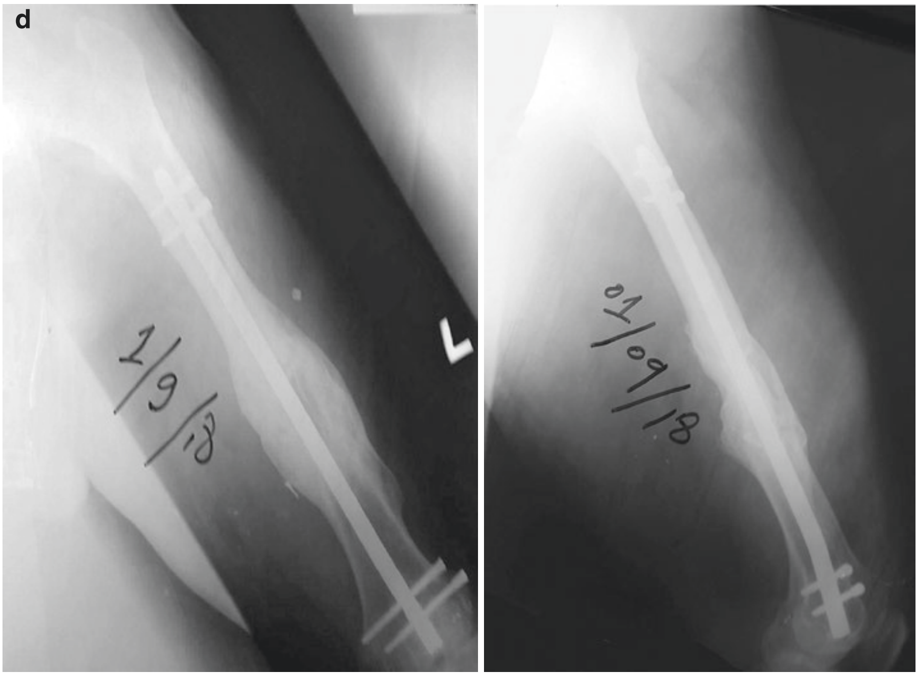

Fig. 41.15 (continued)

Malunions About the Knee

The same principles of accurate intra-articular reduction and fixation that are given above for nonunions about the knee apply to malunions. If pain is the presenting symptom, degenerative changes may well be worse than suggested on X-ray. Osteotomizing a healed intra-articular fragment through the old fracture line is more difficult than mobilizing an extra-articular nonunion and requires adequate exposure. When elevating a depressed fragment, bone grafting should be used to fill the void and add support. Rigid internal fixation allows early mobilization, but when unavailable, temporary fixation with K-wires, Steinmann pins, and immobilization in a cast for 6–8 weeks is a viable alternative. Joint mobilization can be started after the pins are removed, but weight-bearing waits for 3 months.

Malunions of Tibial Fractures

These are common and should be considered for correction if there is malalignment of more than 5–10° varus or valgus or 10–15° or more of angulation in the sagittal plane. Shortening is rarely as great as that seen in the femur. When there is no shortening, the clamshell technique, as described for the femur or closing or opening wedge osteotomies with nail or plate fixation can be used. Simple osteotomy or osteoclasis at the fracture site, percutaneous when possible, fibular osteotomy, manipulation, temporary fixation with pins, and cast immobilization are effective when hardware is unavailable or the surgical environment precarious.

Malunions Around the Ankle

Unless degenerative changes are already visible on X-rays, malunions of malleolar fractures should be addressed in the same fashion as malleolar nonunions. This is technically more challenging as the precise level of medial osteotomy can be difficult to determine, especially if fluoroscopy is not available. Some degree of residual stiffness, even painless fibrous ankylosis, may yield acceptable outcomes. If pain becomes severe, a tibiotalar arthrodesis can be done and will be technically simpler if there has been some anatomical restoration of the joint.

Malunions of the Foot

A painful varus deformity of the hindfoot, seen after a displaced calcaneal fracture, may warrant a Dwyer osteotomy (described below in Deformities of the Foot Requiring Osteotomies). A diagnostic block will help differentiate subtalar joint pain.

Localized metatarsalgia with a painful plantar callus can occur with metatarsal malunions. If symptomatic, an oblique osteotomy of the neck of the affected metatarsal is usually effective. The osteotomy is made from proximal-dorsal to distal-plantar, and early weight-bearing in a stiff-sole shoe allows the prominent metatarsal head to slide dorsally. Transfer metatarsalgia in neighboring metatarsals can occur. If the first metatarsal requires osteotomy, we recommend temporary internal fixation with K-wires in the desired position to prevent displacement.

Correction of Non-traumatic Deformities

Tibial Osteotomies

Tibial osteotomies are commonly indicated for non-traumatic deformities, such as genu varum or valgum arising from degenerative arthritis, rickets, dysplasias, or diaphyseal bowing (https://www.youtube.com/watch?v=bck39CmisY0). Severe deformities are often bilateral, and correcting only one side will achieve little. The second limb should be corrected, 4–6 months after the first, though both sides can be done safely at the same setting, with tourniquets used to restrict blood loss. This latter approach makes nursing difficult if prolonged non-weight-bearing is required.

In the case of severe and/or long-standing deformities, the hip and ankle have usually compensated. Contractures around the hip are not uncommon, but this spherical joint usually adapts. The limitations of ankle anatomy make adapting to new mechanics more proximally less forgiving, particularly in the coronal plane. A plantigrade foot before correction indicates ankle joint adaptation and may require an additional distal tibial osteotomy. The patient should be made aware of the two-phased approach before the first procedure.

Genu Varum or Valgum Deformities

These are common and can be quite severe. Often the question is where to best perform the correction: femur, tibia, or both. If the site of malalignment can be easily identified, the site of correction is obvious. The ultimate goal is for knee and ankle joint lines to be parallel to the floor when standing. Prerequisites include adequate function of the ipsilateral hip and ankle joints (see Chap. 37 for further principles on correction of angular deformity).

Ask for the longest films possible of the entire leg, and from them estimate the precise amount of correction required to align the mechanical axis from the head of the femur through the center of the knee and ankle joints. As a general rule, if the mechanical axis of the femur is 0°, all the correction should be obtained below the knee. If the mechanical axis of the tibia is 0°, the correction should be done above the knee. Otherwise the knee and ankle joints will lose their parallelism.

When X-rays are inadequate, angles can be estimated clinically, although less precisely, by the following: The center of the hip joint is identified and marked. Clinically it is one thumb breath medial to the ASIS or, as some advocate, one quarter of the distance between the tips of the greater trochanters [8]. The knee and ankle joints are also marked. An AP knee X-ray with metallic skin markers defines the joints more precisely. The mechanical axes of femur and tibia are drawn on the skin and the angles measured with a goniometer.

Varus deformity due to degenerative arthritis of the knee is usually corrected by means of a valgus-producing high tibial osteotomy with overcorrection of 5°. Significant valgus deformity due to the same cause is managed by varus-producing distal femoral osteotomy. Varus or valgus deformity due to proximal tibial malunion is corrected at the malunion site itself to bring the knee joint parallel to the floor. Occasionally, deformities are so severe that osteotomies are needed on both sides of the joint.

Osteotomies can be dome or wedge type. In general, closing wedge osteotomies heal faster than opening wedge osteotomies, do not stretch neurovascular structures, allow early weight-bearing, and are generally preferred unless leg shortening is an issue. When osteotomies are done on both sides of the joint, an opening femoral wedge and a closing tibial wedge—with the tibial wedge used to prop open the femoral one—are much less at risk of winding up with a significant leg length discrepancy. This can be supplemented by a piece of fibula harvested at the time of osteotomy.

A sterile goniometer is valuable at the time of surgery. One solution is to create a makeshift one (see Appendix 6). The goniometer allows K-wire insertion above and below the proposed osteotomy site at predetermined angles, so they will be parallel after the osteotomy. Positioning these wires parallel in the frontal or sagittal planes helps control rotation. These improvised markers are useful if a blade plate or DCS implant is used for internal fixation in the distal femur. Without fluoroscopy, proper positioning of hardware can be technically demanding, especially the blade plate. Our preferred technique is illustrated in Appendix 6.

If blade plates or DCS implants are not available, regular DCPs can be bent usually through the fourth or fifth hole of an eight- to ten-hole plate to make a blade plate. This is much easier with small fragment DCPs, in which case two plates can be used side by side if necessary. Unbent DCPs can also be used as condylar plates, but fixation in the distal fragment is usually limited to two screws. Fixation of the osteotomy can be achieved with Steinmann pins if no other implant is available. The pins are incorporated in a long-leg cast for 6–8 weeks. After removal of cast and pins, knee motion is started, but weight-bearing, particularly for opening wedges with grafts, should wait until 3 months from initial operation.

L- or T-shaped buttress plates are adequate for fixing high tibial closing wedge osteotomies. Blade plates can be contoured from small fragment DCPs or one-third tubular plates, stacking two together to increase their strength. If fixation is rigid, early knee motion is possible but not full weight-bearing. Staples, compression screws, and even temporary pinning and casting are acceptable alternatives. Some surgeons recommend a well-molded cylinder cast and immediate weight-bearing for their closing wedge osteotomies.

Dome Osteotomy

A dome osteotomy can be used for correction in the proximal tibia or distal femur. The healing time is faster due to the increased area of bone contact, and the correction may be more precise as the fragments can be “dialed in” at any desired angle. In theory, internal fixation should be on the concave side of the deformity, but when strong implants such as blade plates or condylar plates are available for the femur, lateral placement is adequate. In combined tibial and femoral dome osteotomies, a lazy S incision—starting laterally over the distal femur, curving over the distal pole of patella, and following the posteromedial crest of the proximal tibia—affords better exposure to both bones than a classic anterior midline incision.

There should be no more than 2 cm of height between the dome apex and borders of the dome. For the femur we prefer a distal pointing (smile) dome at the metaphyseal-diaphyseal junction, as there is more cortical bone stock in the distal fragment for fixation. Bicortical holes are drilled from anterior to posterior along the planned dome line and connected with a small osteotome. Well-positioned retractors and knee flexion prevent injury to the posterior neurovascular structures. The osteotomy is completed with forceful manipulation, leaving a posterior periosteal hinge. The osteotomy is temporarily fixed with two crossed Steinmann pins. The alignment is rechecked and the osteotomy internally fixed. The new knee center is used to assess how much correction is needed on the tibial side.

Different dome osteotomies have been described for the tibia (above or below the patellar tendon, smile, or frown). We prefer to go through more cancellous bone, so we routinely use a proximal apex (frown) above the patellar tendon insertion. The dome technique is the same as above. All efforts are made to keep a posterior periosteal hinge at the osteotomy, and the distal fragment is rotated on the proximal fragment until the centers of the knee and of the ankle are in line. Temporary fixation with Steinmann pins allows an assessment of the overall alignment, including a look from the foot of the table before definitive fixation.

Careful disruption of the proximal tibiofibular joint capsule is preferable to fibular osteotomy to avoid injury to the motor nerve of the extensor hallucis longus. Working a Cobb or Key elevator from distal to proximal between the lateral tibia and the fibular head will avoid injury to the interosseous vascular bundle distally. Rigid fixation is preferred as it allows earlier range of motion. If no hardware is available, temporary Steinmann pin fixation and a well-molded long-leg cast are acceptable alternatives. Even with rigid fixation, when both tibia and femur have been corrected, a posterior gutter splint or a bivalved long-leg cast is used for 7–10 days for comfort. The surgeon must be on the lookout for a postoperative compartment syndrome. Weight-bearing is started at 6 weeks.

Deformities of the Foot Requiring Osteotomies

Varus deformity of the hindfoot is common in under-corrected clubfeet and occasionally from a displaced calcaneal fracture. A lateral closing wedge osteotomy of the calcaneus (Dwyer-type) is a simple and effective procedure and restores a more physiological mechanical environment (https://www.youtube.com/watch?v=lX-mR6Tf678).

Secure internal fixation allows early range of motion and weight-bearing at 3–4 weeks. Or use a large Steinmann pin within a well-molded short-leg non-weight-bearing cast for 6 weeks. Progressive weight-bearing begins after pin removal.

Valgus deformity of the hindfoot can be seen in symptomatic flatfeet, in overcorrected clubfeet, in tarsal coalition, or as a sequela of polio.

Box 41.3 Dwyer Osteotomy

- Five to six centimeter oblique incision, 2 cm distal to tip lateral malleolus, centered along posterior cortex.
- Do not undermine the skin.
- Identify sural nerve and protect.
- Incise tissues to expose os calcis subperiosteally.
- Place retractors prox and distal to the calcaneal body.
- Remove a ±1 cm laterally based wedge.
- Preserve medial hinge.
- Close wedge with staples, Steinmann pin, or screws.

Its management is similar to osteotomies done for lateral column lengthening (see Chap. 35 neglected club feet).

Cavus deformity of the hind- and midfoot is often associated with central or peripheral neuromuscular conditions. A common associated complaint is metatarsalgia, especially with excessive pronation or supination of the forefoot. Depending on the location of the deformity, correction is with an anterior closing wedge osteotomy at either the talonavicular and calcaneocuboid joints or the naviculo-cuneiform-cuboid joints, accompanied by a thorough release of the plantar fascia. Fixation with screws or staples is preferred, but pins and/or wires and cast immobilization are also effective. If, after correction, a “cock-up” deformity of the great toe MTP joint cannot be reduced passively, IP joint fusion and rerouting the EHL tendon through a tunnel in the neck of the first metatarsal will correct the deformity (Jones suspension procedure).

Salvage of Post-traumatic or Degenerative Joint Problems

Arthrodesis

Fusion of large joints is a rare salvage procedure in high-income countries because better alternatives are almost always available. This is not the case in austere environments, and surgeons should be comfortable with both the indications and techniques of arthrodesis, as this is often the only means to provide pain relief and stability.

Normal or near-normal motion of the joints adjacent to the arthrodesis is a prerequisite; near-normal function of the contralateral limb is desirable. As a general rule, distal joints tolerate the stress of a fusion better than proximal ones. It is essential that the patient understands that a successful fusion alleviates pain but results in complete and irreversible loss of motion with specific physical limitations. It is important to factor in the sociocultural context. In some societies, particularly those living near the floor, arthrodeses, like amputations, are almost never accepted. Some surgeons advocate immobilizing the joint in question in plaster in the position of the anticipated fusion in order to confirm acceptance of the residual function allowed by the procedure. We insist that the patient, with the help of an interpreter if necessary, repeats to us exactly what will happen to him or her after surgery before we mutually agree to proceed. An iliac crest should always be prepped and available for bone harvest whenever any fusion of a major joint is attempted (Appendix 3).

For many joints, the only alternative to arthrodesis is resection arthroplasty, which preserves some degree of motion but may leave the patient with residual pain, weakness, and/or instability. It is usually technically more difficult to convert a failed resection arthroplasty to a fusion. Nonetheless, many patients prefer to take their chances with an elbow or hip resection arthroplasty than a fusion.

Shoulder

There is no universally accepted consensus on the best position for a glenohumeral arthrodesis, since residual motion will depend on scapulothoracic mobility. Rowe recommended 20° abduction, 30° flexion, and 40–50° internal rotation. The procedure is technically demanding, and since the upper extremity represents a long lever arm of deforming forces, rigid internal fixation is necessary but may be difficult if disuse osteoporosis is present or the proper hardware lacking.

We prefer a two-incision technique, allowing better purchase on the scapular spine posteriorly with a neutralization plate. The patient is placed in a lateral position, and through a standard deltopectoral approach, the subscapularis and supraspinatus are detached from the humerus and tagged, and the capsule is widely opened. The joint is debrided and the articular surfaces of the glenoid and humeral head are prepared for maximum apposition in the desired position.

A transverse posterior incision is made along the scapular spine. Subperiosteally expose the superior aspect of the spine by mobilizing the belly of the supraspinatus superiorly, as far as the posterior acromion. The previously cut and tagged supraspinatus tendon, now with the muscle detached, is allowed to retract proximally, opening a tunnel between both wounds. Temporary fixation of the joint with large Steinmann pins allows the surgeon to assess the proposed position. A sterile pillow under the elbow is helpful during the entire fixation process. Long, short-threaded cancellous screws are used to compress the humeral to the glenoid bed. The strongest available large fragment DCP or small fragment DCP is molded to fit into the supraspinatus fossa and onto the anterolateral aspect of the proximal humerus. At least four screws are used in each fragment, with iliac crest graft as necessary. The supraspinatus tendon is reattached over the plate. When there is massive rotator cuff damage with proximal migration of the humeral head, an acromioplasty may be necessary to make room for the plate. Drainage is recommended.

Before being awakened from anesthesia, the patient is put in a shoulder spica splint. This is prepared 1 or 2 days prior to surgery by placing the arm in the anticipated fused position and making a shoulder spica cast, using two supporting struts between the arm and body segments of the cast. The spica is bivalved, connecting the medial half that supports the arm to the part around the torso. The borders are trimmed, padded, and taped for comfort. The shoulder abduction splint is secured after surgery using elastic bandages and should remain in place for 6 weeks. When removed for dressing change or personal hygiene, the elbow should be supported at all times. The patient is encouraged to move the wrist and fingers and do isometric exercises.

Elbow

Obtaining a solid elbow fusion is technically difficult: the bones are slender and the lever arm long. Most elbow fusions are performed for unilateral arthrofibrosis or ankylosis in a dysfunctional position (i.e., <90° flexion). The recommended position is 90–100° flexion [9]. It is important to maintain or regain as much pronation and supination as possible. For this reason, excision of the radial head is done through a separate, lateral anconeus approach. A straight posterior approach is used to reach the medial side of the joint and protect the ulnar nerve. The anterior, medial, and posterior aspects of the joint and distal humerus are exposed subperiosteally. The triceps tendon can be reflected by more than half its width to facilitate exposure or the olecranon osteotomized at the level of the posterior humeral cortex and the fragment used as bone graft. Retractors are positioned to reflect and protect the anterior structures. The joint is debrided, using valgus stress to facilitate the exposure.

The distal humerus is “squared off,” and the olecranon articular surface is prepared to create a male/female fit. The elbow is placed in the desired position and bone apposition assessed. When joint destruction is severe, as after septic arthritis, we do not hesitate to shorten the distal humerus to above the olecranon fossa, to provide a sturdier bed. The medial epicondyle can be osteotomized and used as bone graft anteriorly with additional iliac graft as needed, and the radial head is excised. Pronation and supination may be impaired, as the radius often migrates proximally. This negative feature is offset by a higher likelihood of a successful fusion.

Fixation is secured with a ten-hole reconstruction plate or a small fragment DCP contoured to the posterior humeral cortex and the medial side of the proximal ulna. One or two screws inserted in compression outside the plate from the ulna into the distal humerus improve the construct. Alternatively a Steinmann pin can be inserted from the olecranon into the humeral medullary cavity and supplemented with screws, pins, or wires. This tenuous construct is made more secure by adding a four-pin posterolateral external fixator under compression for at least 3 months. A long-arm cast is a poor alternative, and failure rates are high. When internal fixation is solid, a protective back slab can be used for the first 2 weeks, after which pronation-supination exercises are started.

Wrist

Wrist arthrodesis is indicated for pain following injury or infection or, as an alternative to tendon, transfers for neurologic deficits. It does not rely on prolonged sophisticated rehabilitation. The desired position is 20–30° dorsiflexion, lining the third metacarpal with the ulnar border of the radius. Through a straight longitudinal dorsal approach, the articular surfaces of the distal radius, capitate, and proximal second and third metacarpals are removed; the lunate and trapezoid can be “crumpled”—crushed but not excised—with a rongeur. Bone graft is from the distal radius or iliac crest. An eight- to ten-hole small fragment DCP is contoured to maintain the wrist in the desired position and secured over the bone graft (Fig. 41.16). It is desirable to protect the fusion in a short-arm cast for 6 weeks.

If plates are not available, a Steinmann pin can be inserted in a retrograde fashion from the space between second and third metacarpals into the shaft of the radius and supplemented with additional K-wires. With this fixation, a short-arm cast is mandatory for at least 6 weeks and can be continued for an additional 6 weeks. In rare instances where bilateral fusions are indicated, the side responsible for personal hygiene, usually the left, should be fused at 10–20° volar flexion, the other side at 20–30° extension.

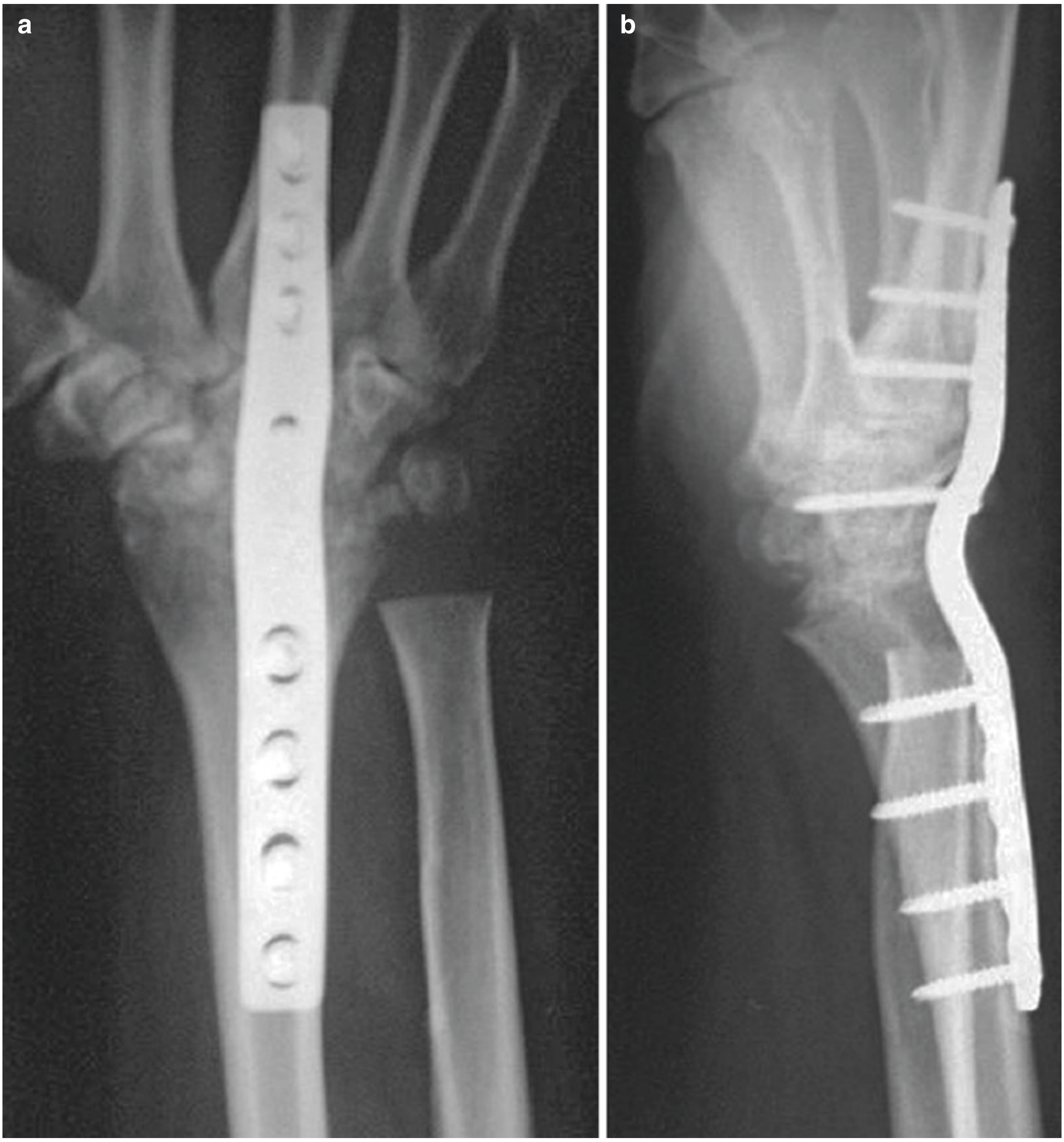

Fig. 41.16 (**a**, **b**) Wrist arthrodesis with fusion plate and screws in desired position of the wrist and of the hardware. A small DCP plate or a reconstruction plate work just as well. Note that the distal ulna has been resected and used as a bone graft

Thumb

Carpometacarpal (CMC) fusion is fixed in a position of near maximal opposition. Metacarpophalangeal (MCP) and interphalangeal (IP) joints should be fixed in 25–30° flexion. Condyles on both sides can be removed with small bone cutters and the opposing surfaces fixed in the desired position with small lag screws, K-wire and interosseous wiring, or crossed K-wires. A thumb spica is used for 6 weeks.

Fingers

MCP joint fusion of the index through little fingers is rarely indicated, as their mobility is essential for full finger function. However, if necessary, around 30° flexion is the recommended position. The proximal IP joints should be fused at 40–50° flexion, increasing flexion from the index to the little finger to maintain the normal cascade. The distal IP joints are fused at 15–20° flexion. Internal fixation is as described for the thumb.

Hip

Successful hip arthrodesis has a long track record of satisfactory pain relief. Secondary degenerative changes of the lower spine and ipsilateral knee are well-documented long-term ill effects. Females of reproductive age are particularly reluctant due to fear of obstetric complications. Because of sociocultural reasons, few patients agree to this procedure. Those who do are usually younger patients for whom pain is disabling and prevents gainful employment.

Many techniques are described, both intra- and extra-articular. The choice of technique depends on multiple factors: the surgeon's comfort zone and experience, the amount of remaining bone stock, and hardware availability. In tropical climates, it is preferred to use a technique requiring no external immobilization. The recommended position of fusion is about 30° flexion, neutral abduction-adduction, and 5–10° external rotation.

Our preference is an intra-articular fusion with internal fixation through a posterolateral or anterolateral approach, with the patient in the lateral decubitus position and the iliac crest available for bone graft. A trochanteric osteotomy is made in line with the superior neck. The supra-acetabular area is exposed superiorly and posteriorly as far as possible, avoiding neurovascular structures. The hip is dislocated on the side of the approach, using sharp instruments to remove the articular cartilage. Bone destruction may be so severe that little of the femoral head is left, in which case the neck remnant is used for fusion, with generous quantities of corticocancellous iliac graft.

Different techniques of bone graft supplementation have been described, including using a sliding strip of corticocancellous bone from the supra-acetabular area (similar to the Blair ankle fusion), using the greater trochanter itself, or even a segment of fibula. Preoperative X-rays should alert the surgeon that bone loss might challenge any improvisational skills. The hip is reduced and maintained temporarily in the desired position with Steinmann pins. Sterile pillows are helpful in supporting the limb, while the surgeon assesses the limb position from all angles. Definitive fixation is achieved with three to four trans-articular short-threaded 6.5 cancellous screws in compression. It is important that a strong assistant supports and maintains the limb in the desired position throughout the entire internal fixation process—a tedious but necessary task.

Ideally, the construct is further fixed with a well-molded cobra plate from the supra-acetabular area to the lateral femoral cortex, including at least ten cortices on each side. One long DCP contoured and applied to the lateral femoral cortex is an acceptable alternative if proximal purchase is adequate. A second DCP can be used more anteriorly and is contoured to lie on the anterolateral femur. Rigid fixation is mandatory because of the large forces crossing the joint. Early knee joint motion is encouraged, but weight-bearing should not start before 12 weeks.

In our experience, hip arthrodesis should not be attempted unless adequate internal fixation hardware is available. Steinmann pins, K-wires, screws alone, external fixation, and spica casts have a high failure rate, and salvage is difficult. An exception is in children, following acute or subacute septic arthritis with severe joint destruction, where spica cast immobilization can yield a spontaneous fusion or ankylosis in good position.

Knee

With normal adjacent hip and ankle joints, a knee fusion provides a stable painless limb for unassisted ambulation. With a knee fusion, kneeling for prayer, or the mobility to independently get up from and down to the floor, is possible only if the opposite leg and both upper extremities are functionally normal. If poor knee function made such motions difficult or painful before, not much is lost, and patients may accept the procedure more easily. The desired position is about 0–10° flexion and 5° valgus.

Correction of severe flexion deformities or contractures or chronic dislocations by shortening may put the neurovascular (NV) structures at risk. In these cases, in order to protect the neurovascular structures, it is safer first to perform a release, followed by skeletal traction, or serial casting aimed at achieving progressive correction before the definitive fusion. Careful neurovascular monitoring during the correction is mandatory.

Mild to moderate deformities can be corrected in a single setting. An anterior approach is preferred, everting the patella to debride the joint. The distal femoral condyles are removed with large osteotomes, while the knee is flexed and periosteal elevators are placed posteriorly to protect the NV bundle. The same is done with the proximal tibia, removing the cartilage to just below the subchondral line. Angular deformities are corrected by removing bone wedges, which further relax the posterior soft tissues.

Achieving good position and alignment is more difficult than it appears, and one or both bones often need a second cut. Temporary fixation with Steinmann pins allows assessment of the position. Definitive fixation is best achieved internally, with two large cancellous lag screws inserted in a crossing pattern from above the medial and lateral epicondyles with additional screws added from below the tibial plateaus. The construct is neutralized with a long large fragment DCP applied anteriorly on the femur and contoured to the anterolateral tibia (Fig. 41.17).

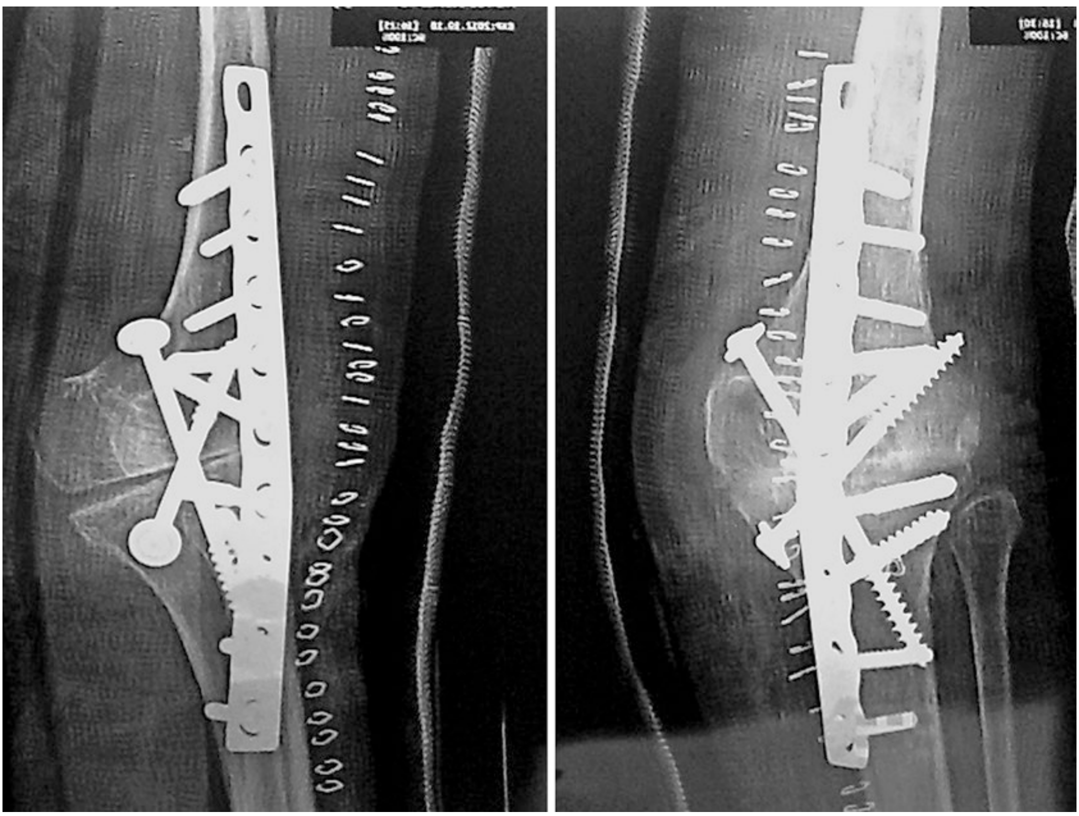

Fig. 41.17 Post-op X-rays of knee fusion with compression screws and anterior neutralization plate. The alignment is good in the frontal plane, but there is some recurvatum in the sagittal plane, not the desired 5° of flexion. This 62-year-old woman had polio in both legs as a child but was ambulatory with only a walking stick until she fell 3 years before. She was not able to resume walking because of a missed quadriceps tendon tear. With the knee fusion, she returned to full painless WB at 6 weeks with her stick

Removing part of the anterior patella groove makes plate application easier. Alternatively, two plates can be used, especially in poor quality bone, and the patella can be resected.

Rigid fixation in compression allows almost immediate partial weight-bearing, with progression to full weight-bearing after 6 weeks. External fixation in compression using frames such as the one described by Charnley can also give satisfactory results. When fixation is done with screws alone, staples, Steinmann pins, or any combination, a well-molded cylinder cast can permit early weight-bearing and is another acceptable option (Fig. 41.18).

When there is associated subtalar DJD, a tibio-talo-calcaneal fusion is indicated. The ankle is approached anteriorly and debrided and, if necessary, corrective osteotomies performed. Retrograde nailing from the plantar aspect of the foot provides secure internal fixation (Fig. 41.19). Where there are no nails, a stout Steinmann pin can be substituted and supplemented by a few screws from the distal tibia to the body of the calcaneus or additional pins (Fig. 41.20). The subtalar joint will usually fuse spontaneously, and additional surgical exposure is not necessary. Pins can be removed at 6 weeks, with a NWB cast for another 6 weeks.

Ankle

The ankle tolerates fusion well. When malunion is the indication, corrective osteotomies or bone resections are indicated to restore normal alignment of the hindfoot. The approach is anterolateral and the desired position of arthrodesis is 0–5° plantar flexion, 0–5° external rotation, with the talus as posterior as possible under the tibia. The distal tibia and talar dome are removed with a wide osteotome, and the medial and lateral borders of the talus and the malleoli are shaved.

Excessive anterior subluxation of the talus under the tibia should be avoided since this reduces the contact area and changes the hindfoot contour posteriorly. The talus can be kept in the desired position with a temporary calcaneotalotibial Steinmann pin. Two crossed lag screws directed from the tibia into the talar body and transverse screws from the malleoli into both the tibia and talus give good fixation. With severe joint destruction, additional bone graft can be harvested from the iliac crest.

A 1–1.5 × 3–4 cm cortical strut from the anterior tibia slid into a prefashioned trough in the talar dome and neck can add stability (Blair fusion) with cancellous bone harvested from the distal tibia as needed. Additional fixation can be added with a small contoured T plate or a one-third tubular plate anteriorly. A short-leg non-weight-bearing cast is worn for 3 months until clinical consolidation.

Foot

Arthrodeses around the hindfoot are indicated for pain relief, deformity correction, or both. When pain without deformity is the indication, temporary relief with selective injections of local anesthetic in the suspected joint is a good predictor of a favorable outcome with fusion. Most surgeons agree that fusing one of the three hindfoot joints functionally blocks the other two, commonly leading to premature DJD and making a triple arthrodesis preferable to a single-joint fusion (See Chap. 35).

We prefer the transverse Ollier approach, exposing the sinus tarsi and reflecting distally or removing the belly of the short extensor muscle. The peroneus brevis forms the margin of the exposure laterally, under which a retractor is inserted. The long extensor to the fifth toe forms the margin anteriorly. A retractor can be inserted under the dorsal soft tissues, all the way to the medial aspect of the foot, a maneuver more easily performed with the ankle in dorsiflexion. For fusion in situ, bone trephines, such as those seen in the Cloward cervical fusion set, work very well. The trephine is centered over the joint, and the cavity is filled with a bone plus harvested from the iliac crest with a trephine 2 mm wider. For deformity correction, the talocalcaneal, talonavicular, and calcaneocuboid joints are opened and debrided. A small lamina spreader improves the exposure. As a general rule, whether the

Fig. 41.18 (**a**) Clinical and (**b**, **c**) radiographic appearance of a 14-year-old boy with a fixed 65° recurvatum of his left knee, secondary to a septic arthritis. (**d**) Postoperative X-ray after arthrodesis and fixation with one staple and two Steinmann pins. (**e**) Clinical appearance in his postoperative cast. (**f**) X-ray appearance at 8 weeks, at which time, the pins were removed, and the patient put in a cylinder cast for 3 more months. (**g**, **h**) Clinical appearance at 1 year. The patient ambulated without pain or walking aids. A dressing is covering an unrelated injury. No X-rays were obtained, as there was a shortage of X-ray film

Fig. 41.18 (continued)

Fig. 41.19 (**a**) Right ankle DJD secondary to post-traumatic avascular necrosis of the talus. There was also significant loss of subtalar motion. (**b**) A retrograde tibio-talo-calcaneus fusion was done with a dynamically interlocked IM nail

deformity is varus or valgus, under-correction is better than overcorrection. We prefer to remove the two anterior joints—talonavicular and calcaneocuboid—in one slice, with an oscillating saw or a wide osteotome.

The subtalar joint is more difficult to expose posteriorly. A lamina spreader in the sinus tarsi or even two Steinmann pins in the talus and calcaneus, used as joy sticks, allow easier exposure of the posterior facet which can be curetted or osteotomized. A varus deformity is corrected with a laterally based closing wedge osteotomy, with great care taken to avoid injury to the neurovascular bundle posteromedially. A valgus deformity

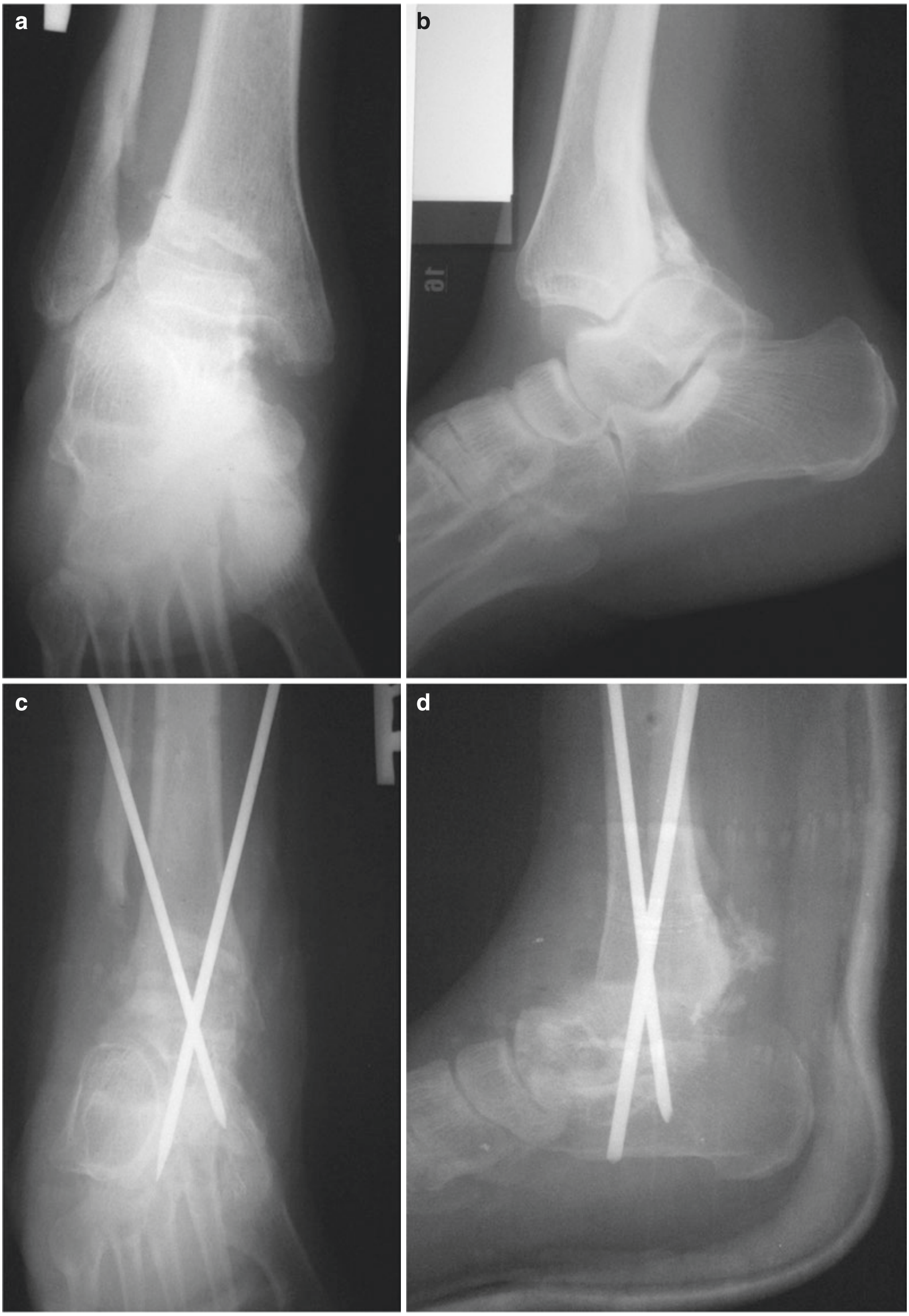

Fig. 41.20 (**a**, **b**) Post-traumatic ankle DJD requiring fusion. (**c**, **d**) In the absence of adequate implants, internal fixation is achieved with crossed Steinmann pins that will be removed at 12 weeks

can be corrected with an opening wedge osteotomy using resected bone or a small piece of fibula to maintain the opening wedge. In this case, a lamina spreader or stacked osteotomes can help to keep the wedge open.

When correction is achieved, the joints are stabilized with staples, screws, pins, and/or K-wires, and the foot is immobilized in a short-leg cast that is immediately bivalved, and the leg is elevated. When swelling has resolved, the cast can be completed. Pins and wires are removed at 6 weeks, a new cast applied, and the patient remains non-weight-bearing for a total of 3 months. Soft tissue releases such as Achilles lengthening, posterior joint release, tibialis posterior lengthening, plantar release, anterior tibialis split transfer, or a combination should not be overlooked.

Fixed equinus is addressed by combining a posterior release with an anterior (or dorsal) closing wedge osteotomy, with in situ fusion and fixation of the subtalar joint. Cavus deformities are corrected with an anteriorly based closing wedge osteotomy, performed more easily through a longitudinal anterior approach than an Ollier approach, in conjunction with an extensive plantar release.

Neglected displaced Lisfranc fracture-dislocations—tarsal-metatarsal—can be disabling. When a single ray is involved (usually the first), reduction is fairly easy, with appropriate soft tissue releases and joint excision. Displaced fracture-dislocations of the entire row (splayed or windswept) are more challenging. Most commonly some metatarsals are also displaced anteriorly, sometimes even overriding the cuneiforms. A single transverse incision disrupts the venous circulation, so we prefer two to three longitudinal incisions. Each joint is opened, debrided, mobilized, and shortened if needed. The base of the fifth metatarsal can be difficult to mobilize, due to retraction of the peroneus brevis tendon. This tendon can be lengthened or cut, if necessary, and sutured proximally to the peroneus longus tendon. Curettage of the articular surfaces is usually sufficient, and bone graft is seldom needed. Each joint is reduced and fixed separately with screws and/or K-wires. Pins can be removed at 6 weeks, but weight-bearing is allowed only at 3 months.

Fusion of the first metatarsophalangeal joint (MTP) may be indicated for management of hallux rigidus, failed hallux valgus surgery, post-traumatic DJD, or inflammatory conditions. Compared to a resection arthroplasty, a successful fusion may more reliably eliminate pain but with some mild decrease in push-off strength. The ideal first metatarsal-phalangeal position is 25–30° extension and 10–15° valgus. These recommendations are made for patients in countries where shoes are worn, such that the toe would be slightly extended with ambulation to prevent painful callus formation or IP joint arthritis. Most patients in poor countries walk barefoot or with sandals. If this is the case, the fusion should be done with less extension: 15–20° with respect to the first metatarsal to avoid a cocked-up toe. Internal fixation with a small plate or a screw inserted from the plantar aspect of the metatarsal neck into the medullary canal of the proximal phalanx or two crossed screws is preferred, but crossed K-wires and casting are also effective (Fig. 41.21).

Arthroplasty

Joint pain and stiffness in the developing world can frequently be traced to delays in initial management or improper early interventions. Arthroplasty is a procedure to reconstruct or replace a malformed or degenerated joint. The goals of these procedures are to reduce pain, preserve motion, and provide joint stability. In reality, not all these goals are equally achievable with the various techniques that will be discussed. In order to optimize the outcomes, the surgeon must first understand the needs and expectations of the patient and place these in the context of the disability being addressed. By setting realistic expectations at the outset and properly matching the procedure to the patient, the pathology, and the environment, outcomes can be maximized even when resources are limited.

Fig. 41.21 (**a**) Symptomatic hallux rigidus. (**b**, **c**) AP and oblique views after arthrodesis with two crossed screws. (Courtesy of Stephen K. Benirschke)

Resection Arthroplasty

Resection arthroplasty involves the removal of joint surfaces with varying amounts of the bone in order to create a space between the bone ends. Goals are to decrease pain and maintain motion; however, stability is sacrificed. Resection arthroplasty is frequently used as a salvage procedure in chronically infected joints or in those where pain and stiffness prevent useful function.

Acromioclavicular Joint

Painful degenerative arthritis of the acromioclavicular joint, unreduced acromioclavicular dislocations, and malunited fractures of the distal clavicle are conditions amenable to distal clavicular resection. Remove at least 2–3 cm of the bone from the distal clavicle, taking care to preserve the coracoacromial ligaments. Reconstruction of deficient coracoacromial ligaments to stabilize the distal clavicle is rarely indicated.

Shoulder

When there is inadequate bone stock for arthrodesis or shoulder stability is not a question, resection arthroplasty of the shoulder—Laurence Jones tenodesis—[10] can provide pain relief and active motion that is limited, but functional. Reattachment of the rotator cuff muscles to the proximal humerus in order to impart some active control improves this procedure.

Through a delto-pectoral approach, the subscapularis tendon, supraspinatus tendon, and conjoined tendon of the infraspinatus and teres minor are isolated with or without attached humeral bone, depending on the underlying pathology. The humeral head and, if necessary, a portion of the proximal humerus are resected and the bone surface smoothed. Decorticated and appropriately located grooves in the proximal humerus assist in reattaching the separate rotator cuff tendons or bone-tendon segments with heavy nonabsorbable suture. Any residual capsular tissue is plicated in the interval between the resected humerus and the glenoid. The deltoid is meticulously repaired to the acromion, and the arm is placed in 45° abduction and neutral rotation and immobilized for 4 weeks in a shoulder spica splint of the type previously described for shoulder arthrodesis. An additional 2–4 weeks of night splinting will further protect the repair if it is felt to be tenuous.

Wrist

Proximal row carpectomy (PRC) is the equivalent of a resection arthroplasty of the wrist. Where the primary goal is a stable, fixed, pain-free wrist joint, arthrodesis is more reliable. PRC is suited for the management of scaphoid nonunions and moderate radiocarpal arthritis. This straightforward procedure can be performed using a dorsal longitudinal incision through the third compartment. A capsular incision is made along the ulnar border of the extensor carpi radialis brevis tendon and the adjacent radius exposed subperiosteally. The scaphoid, lunate, and triquetrum are removed, in that order, taking care to preserve the volar radio-scaphoid-capitate ligament. After this excision, the proximal articular surface of the capitate articulates with the lunate fossa of the radius. A short-arm cast is used for 3–4 weeks, followed by a volar wrist splint for 3–4 weeks, while range of motion exercises are started. Grip strength will be reduced 20–30% and motion reduced 40–50% following this procedure, but pain relief with preservation of a functional range of motion is usually achievable.

Hip

Resection arthroplasty of the hip is often incorrectly termed the "Girdlestone procedure" [11]. As currently practiced [12, 13], the head and neck of the femur are removed and the abductor muscles preserved. Plication of the joint capsule is carried out if sufficient tissue can be mobilized (Fig. 41.22). Any of the commonly described surgical approaches to the hip joint can be used (https://www.youtube.com/watch?v=BgEmMdcjsck&list=PLtbxkVzxxrBizrARMkf3EYS5PwP3

Fig. 41.22 Resection arthroplasty of the right hip, with greater trochanter abutting the acetabular rim

wR6LT). To our knowledge, post-op skeletal traction is not necessary.

Hip motion is encouraged within the limits of pain, and patients are started on partial weight-bearing with crutches. Eventually, most patients are able to walk with only the use of a single crutch or cane. A 3–5 cm shoe lift partially corrects the resulting limb shortening. Pain relief and function can be surprisingly good.

Toes

Metatarsal head resection in the lesser toes is an effective intervention for severe forefoot deformity arising from rheumatoid arthritis or trauma (Fig. 41.23). Resection of the proximal portion of

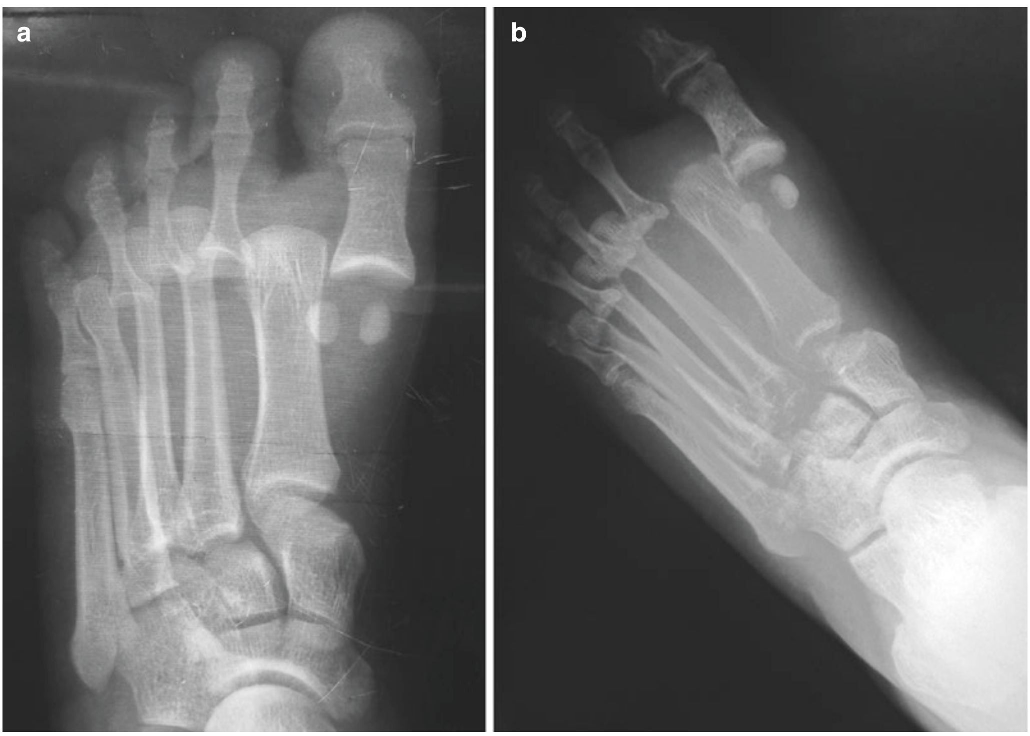

Fig. 41.23 (**a**) (*left*) X-ray of the foot after being run over by the tire of a car with open plantar-medial dislocations of MT-P joints 1–4. X-ray on the *right* was taken 2 months later. Note periarticular osteoporotic midfoot changes. (**b**) Appearance of the foot at time of surgery: wound still open but clean, swelling under control, but soft tissues deeply wrinkled and brawny. (**c**) X-ray post removal of MT heads and realignment of rays

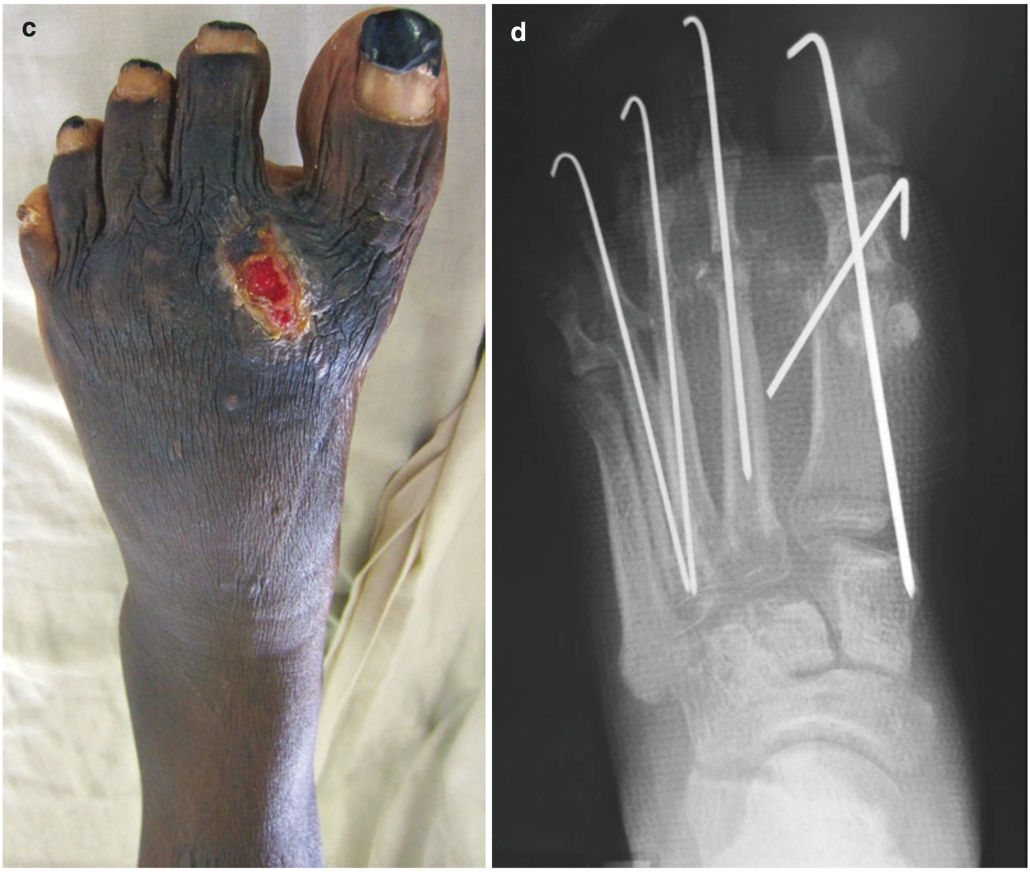

Fig. 41.23 (continued)

the proximal phalanx of the great toe may restore pain-free motion when there is severe arthritis or infection in the MTP joint (Keller procedure). The advantage over MTP joint fusion is that no internal fixation is required and there is no risk of a painful nonunion. The disadvantage of resection arthroplasty is shortening of the great toe and loss of push-off strength.

Interposition Arthroplasty

Interposition arthroplasty involves the placement of biologic or non-biologic material between the surgically removed joint surfaces. The goal is to promote motion and prevent pain from direct bone-on-bone contact. Autogenous tendon, the skin, and fascia are the materials most often used for interposition in austere settings.

Elbow

The ideal elbow motion to accomplish ADLs is a 100° arc of motion with no more than a 30° flexion contracture and at least 120–130° elbow flexion and at least 50° pro-supination. To maintain some motion, interposition arthroplasty is sometimes chosen rather than arthrodesis as a salvage procedure for severe elbow afflictions. If successful, the procedure can result in elbow motion sufficient for self-care and light tasks. Bony ankylosis and gross instability are contraindications, and adequate bone stock in the distal humerus is a prerequisite.

Using a pneumatic tourniquet high in the upper arm, make a long posterolateral incision over the distal humerus and proximal forearm [14]. Proximally, the lateral humeral shaft is exposed between the triceps and brachial radialis, and distally, the deep incision enters the interval between the anconeus and the extensor carpi ulnaris. The common extensor mechanism and lateral collateral ligament are detached from the lateral epicondyle and the anterior capsule released; if possible, the medial collateral ligament is preserved. The distal humerus is debrided of osteophytes and smoothed with rongeurs. The radial head is preserved, if possible, but resected if necessary to achieve better forearm pronation and supination.

A cutis graft can be harvested from the bleeding bed created by raising a split thickness skin graft, removing a swath of underlying epidermal-dermis of up to 5–6 cm^2, and replacing the epidermal graft to cover the exposed subcutaneous tissue [15]. Alternatively, the cutis graft can be prepared from a full thickness ellipse of the skin excised from the groin, where the defect is closed primarily as with a FTSG. The superficial, or skin, side of the cutis graft is placed against the cancellous surface of the humerus and sutured through small drill holes along the radial and ulnar margins, encasing the distal humerus. The extensor origin is reattached and the wound closed. A back slab is worn for 2 weeks at 90° flexion, followed by a hinged cast, brace, or back slab for another 4 weeks. Twice a day the splint is removed, and gentle passive range of motion exercises are done during the initial 2–4 weeks; at 4 weeks, gentle resisted muscle strengthening is started. While the outcome of interposition arthroplasty is acceptable in most low-demand patients, the results are unpredictable, and incomplete pain relief and stiffness remain in a sizeable minority. Residual instability of the joint can be addressed by the use of a brace to provide medial-lateral stability.

Thumb Carpometacarpal Joint

Painful CMC arthritis of the thumb can be managed by resection of the trapezium alone or by resection with interposition of a tendon graft, using the palmaris longus or a distally based slip of the flexor carpi radialis tendon—the anchovy procedure. The joint is exposed through a longitudinal dorsoradial incision, the sensory branches of the radial nerve protected, and the trapezium resected subperiosteally. The tendon graft is rolled and sutured into a ball with absorbable suture. The graft is sutured to the capsule and the capsule closed. A bulky dressing is applied with a thumb spica splint, and heavy use of the hand is limited for 3 weeks, after which, gradual return to full use is encouraged (https://www.vumedi.com/video/cmc-arthroplasty/)

Replacement Arthroplasty

Replacement arthroplasty involves replacing diseased joint surfaces with an orthopedic prosthesis. In comparison with resection and interposition arthroplasty, replacement arthroplasty is resource intensive. In high-income countries, this procedure is a cost-effective intervention. The potential benefits of total joint arthroplasty are well known in the developing world. In many locales, surgeons are interested in learning these procedures, and visiting surgeons may be asked to perform them. However, for a variety of reasons enumerated below, including cost, replacement arthroplasty in the developing world should be undertaken with great caution. The one exception is unipolar hemiarthroplasty of the hip for femoral neck fracture [16].

Total joint replacement of the shoulder, hip, and knee is less well suited to austere settings due to suboptimal operating room environments, the high cost of implants and instruments, and a limited capability to address short- and long-term complications of these procedures. Prerequisites for a responsibly administered total joint arthroplasty program include a scrupulously sterile operating environment, access to prophylactic antibiotics, focused postoperative rehabilitation, and the ability to manage short- and long-term postoperative complications.

Finally, access to low-cost implants with optimal long-term wear characteristics is required, as well as access to ancillary instrumentation, not only for the index procedure but also if there are complications requiring prosthetic removal. Visiting surgeons should not leave potential

Fig. 41.24 Aseptic loosening of a right THR at 8 years, with impressive osteolysis on both sides of the joint. The patient could not bear weight, and there was no possibility for a revision

problems behind that the local surgeon is not equipped to address. Conversely, in less austere environments, total joint arthroplasties are being performed more frequently, usually in the setting of a lucrative private practice. The resources, knowledge, and skills to manage long-term complications such as aseptic loosening are often lacking, and some patients wind up with a situation as bad or worse than the index disease (Fig. 41.24). The same applies to early complications, where the visiting surgeon may feel pressure from peers and patient to "try something." If surgery is contemplated, it should be kept as simple as possible (Fig. 41.25).

Hemiarthroplasty

Prosthetic replacement of the femoral head in patients with displaced femoral neck fractures is successful in some developing country settings [16]. Low-cost unipolar implants from middle-income country manufacturers can be implanted expeditiously with simple instrumentation, resulting in support-free, independent ambulation in the majority of patients. Whenever possible, cement fixation should be avoided, as it is expensive and difficult to remove. Some practitioners advocate an anterior or direct lateral surgical approach for this operation, in order to reduce the risk of postoperative dislocation with the posterior approach. Protected weight-bearing is begun on the day after surgery in order to reduce the risk of pulmonary thromboembolism. Full weight-bearing, with or without a stick, is usually achieved by 6 weeks. Resection arthroplasty can be readily performed as a salvage procedure for management of adverse sequelae such as infection or prosthetic subsidence.

Fig. 41.25 (**a**, **b**) Clinical and (**c**) radiographic appearance of a 66-year-old patient with a chronically dislocated left TKR. This patient dislocated the first time 6-week post-op and underwent two more unsuccessful surgeries. He was in a wheelchair for almost 3 years. (**d**) Postoperative X-ray after open reduction, extensive lateral release, and medial reefing. The components were not loose, and there was no possibility of revision to a constrained configuration. The patient was immobilized in a cylinder cast in extension for 3 months and is still able to bear full weight at 2 years in a knee brace, but without any knee motion

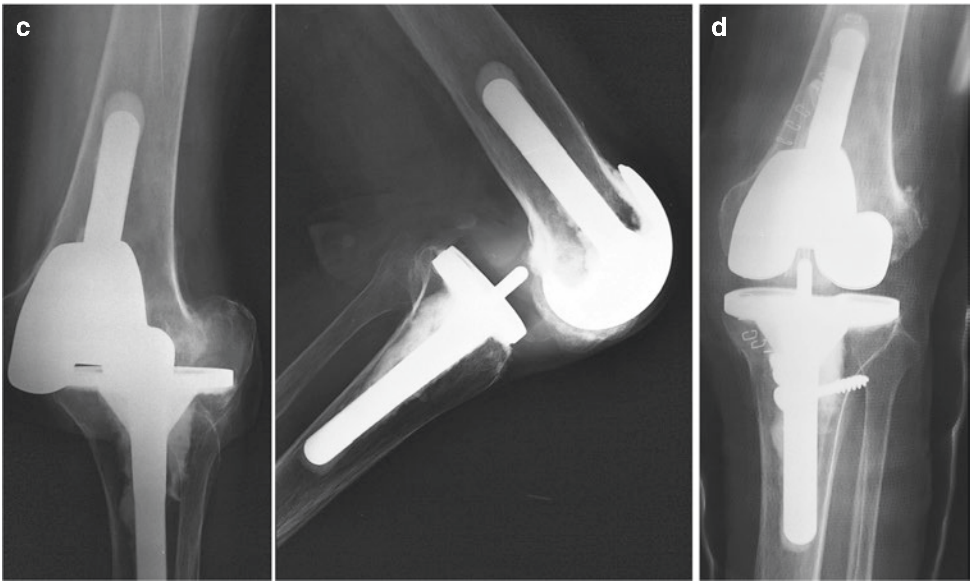

Fig. 41.25 (continued)

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Resources

(https://www.vumedi.com/video/surgical-reduction-of-chronic-shoulder-dislocation/) This video describing an extensive take-down from chronically dislocated shoulder has been described, though we have no experience with it.

42 Bone and Soft Tissue Tumors

Nyengo Mkandawire and John Dormans

Introduction

The aim of this chapter is to outline the challenges of treating bone and soft tissue tumors in resource-limited environments and suggest an approach for management. The global cancer burden continues to rise and is projected to triple by 2030 [1]. In the West cancer survival has increased to more than 70% with modern multidisciplinary oncology services, but without these, outcomes in developing countries remain poor. Patients often present late with advanced disease (Fig. 42.1), and palliative care, if available, may be the only treatment option.

Funding for cancer treatment is limited, as even the basic health needs in LMICs (low- and middle-income countries) are not being met. While 84% of the world's population resides in LMICs, only 5% of global resources to fight cancer go to them [2]. Palliative services are limited by both lack of trained health workers and access to essential drugs such as opioids.

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General Principles

In the absence of advanced technologies for staging and treatment, the clinician must rely on clinical features, basic imaging studies, and limited pathology services (Table 42.1, Fig. 42.2). Features suggestive of malignancy include nonmechanical pain, rapid increase in size, fever, malaise, and weight loss. The prognosis depends on the specific tumor grade, size, and depth, patient age, medical comorbidities, nutritional status, and available resources.

After a thorough history, physical exam, and plain radiographs, lesions suspected of being malignant should ideally be referred to a specialized center and staged prior to biopsy and definitive care, using the Musculoskeletal Tumor Society staging system. However, this relies on MRI to determine marrow extension, CT for local tumor extension and chest metastases, bone scintigraphy for skip lesions and mets, and reliable pathology, all of which are rarely available. In most resource poor environments, staging is limited to plain radiographs, a chest X-ray, and ultrasound to evaluate for abdominal, pelvic, or chest masses.

The biopsy of any lesion suspected of malignancy should be carried out at the treatment center where definitive services will be provided. One option is a core needle biopsy, which can be guided by X-ray, ultrasound, or CT. Open biopsies should be performed by the surgeon who will do the definitive surgery. Cultures should always

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Fig. 42.1 (**a**–**d**) In austere settings tumors often present at an advanced stage, when palliative care is the only option

be taken as chronic osteomyelitis can simulate malignancy and vice versa.

The basic principles of open biopsy should be followed:

- Longitudinal incision.
- Direct approach to the lesion, avoiding contamination of surrounding tissues.
- Adequate hemostasis.
- If using a drain, place it in line with the skin incision.

The soft tissue component associated with a bony lesion should be sampled. Excisional biopsy is contraindicated in cases suspected of being locally aggressive or malignant. With few

Table 42.1 Common musculoskeletal tumors based on age, location within the bone, and radiographic features

1. Patient age				
0–5 years	Benign	Langerhans cell histiocytosis (LCH), osteomyelitis	Malignant	Fibrosarcoma, Ewing sarcoma, neuroblastoma, leukemia
5–10 years		Unicameral bone cyst (UBC), aneurysmal bone cyst (ABC), non-ossifying fibroma, fibrous dysplasia, osteoid osteoma, osteoblastoma, LCH, osteomyelitis		Osteosarcoma, Ewing sarcoma, rhabdomyosarcoma
10–20 years		Fibrous dysplasia, osteoid osteoma, osteoblastoma, non-ossifying fibroma, ABC, chondroblastoma, chondromyxoid fibroma, osteofibrous dysplasia		Osteosarcoma, Ewing sarcoma, adamantinoma, rhabdomyosarcoma
20 years		Giant cell tumor, enchondroma		Chondrosarcoma, lymphoma, leukemia, plasmacytoma, multiple myeloma, metastases (lung, renal, breast, thyroid, prostate)
2. Location				
Epiphyseal	Benign	Chondroblastoma, subacute osteomyelitis, giant cell tumor (adult), osteochondroma, LCH	Malignant	Clear-cell chondrosarcoma (adult), Pagets (adult)
Metaphyseal		Giant cell tumor, unicameral bone cyst, aneurysmal bone cyst, non-ossifying fibroma, osteochondroma, fibrous dysplasia, subacute osteomyelitis, Langerhans cell histiocytosis, chondromyxoid fibroma		Osteosarcoma Fibrosarcoma Chondrosarcoma
Diaphyseal		Fibrous dysplasia, osteofibrous dysplasia, Langerhans cell histiocytosis, subacute osteomyelitis, enchondroma		Ewing sarcoma, leukemia, lymphoma, adamantinoma, chondrosarcoma
Multiple locations		Multiple hereditary exostoses, LCH, fibrous dysplasia, enchondroma, hemangioma		Leukemia, multiple myeloma, metastatic disease
Anterior spine		Eosinophilic granuloma, hemangioma, infection, giant cell tumor, chordoma, Paget's		Leukemia, metastatic disease, multiple myeloma, osteosarcoma
Posterior spine		Osteoblastoma, aneurysmal bone cyst, osteoid osteoma		Metastatic (usually adults)
Pelvis		Aneurysmal bone cyst Langerhans cell histiocytosis		Ewing sarcoma, osteosarcoma, chondrosarcoma, lymphoma
3. What is the lesion doing to the bone?				
Lesional matrix	Ossification, mineralization (calcification), fibrous ("ground glass")			
Border of the lesion (wide or narrow zone of transition)	Circumscribed or geographic		Appears as though a line is drawn around the lesion Slow growing Narrow zone of transition	
	Moth eaten		Small holes in bone Hard to define margin Wide zone of transition Rapid growth	
	Permeative		Wide zone of transition Most aggressive, rapid growth	
4. What is the bone doing to the lesion?				
Cortical response	Slow-growing lesions are well contained, may expand cortex, but do not break through Rapidly growing lesions are not contained and break through the cortex			
5. Periosteal reaction				
Buttress – trying to build up support for bone stress				
Spiculated – "hair on end," fast-growing/aggressive lesions				
Solidification – thick periosteal new bone, slow process				
Onion skin – several layers, fast-growing/aggressive lesions (Ewing sarcoma)				
Interrupted – Codman triangle (triangular area of new bone formation from the periosteum)				

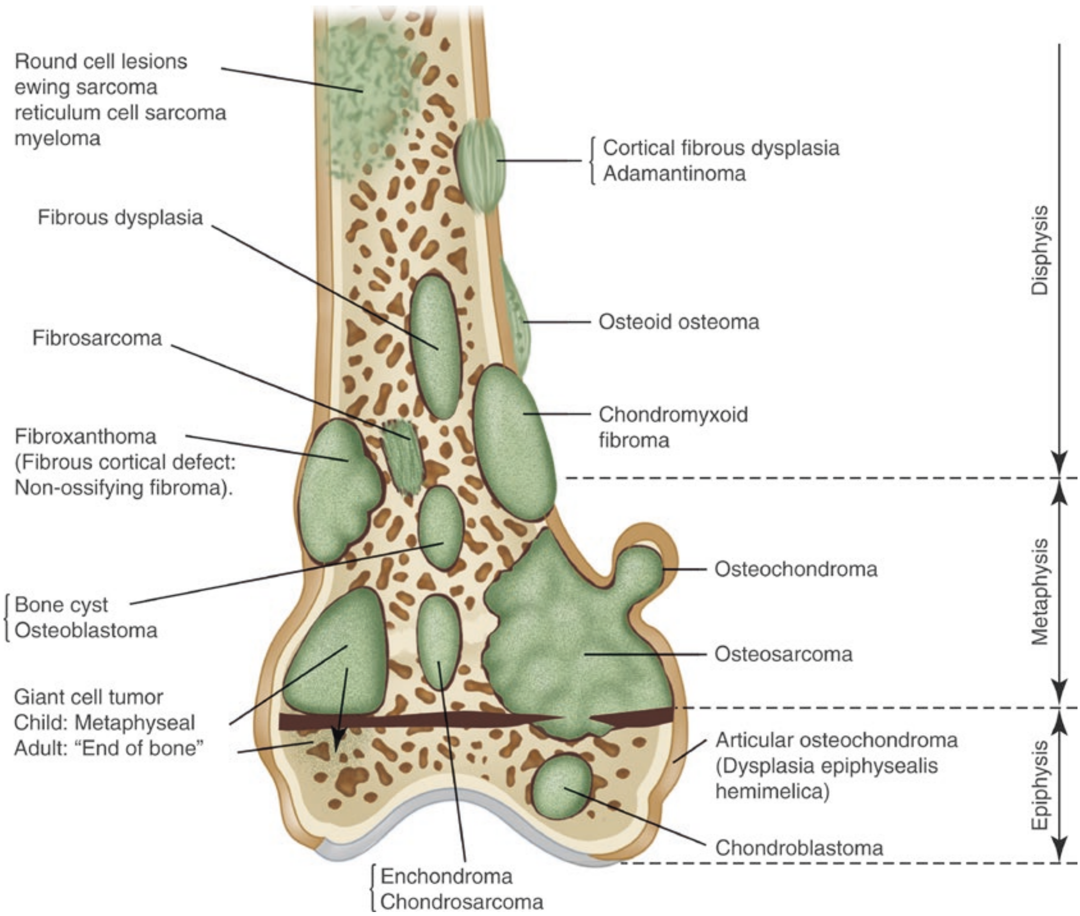

Fig. 42.2 Common bone tumors based on anatomic location

pathologists, samples are usually sent out and must include detailed clinical information.

Treatment of Common Benign Bone Tumors

Benign bone tumors often present as incidental X-ray findings but can also cause localized discomfort or a pathologic fracture. The diagnosis and management of common benign bone lesions are shown in Table 42.2, with examples of the typical radiographic findings in Fig. 42.3. Many of these can be managed outside specialized centers though referral for biopsy is appropriate when the diagnosis is unclear. Symptomatic benign lesions are often treated by marginal excision, with autogenous bone grafting to manage cavitary defects. Impending or pathologic fractures may require internal fixation. Curettage and bone cement (Fig. 42.4) can be considered for benign but aggressive lesions such as giant cell tumor. The risk of recurrence must be considered especially where the lesion extends into the soft tissues, and primary amputation may be a more realistic option for late presenting aggressive giant cell tumors around the knee joint.

Table 42.2 Features of common benign bone tumors

Tumor	Description	Radiographic features	Treatment
Unicameral bone cyst	Fluid-filled cystic lesions	70% in proximal humerus or proximal femur	Treat fracture first, and then decide between observation and active treatment
	Metaphyseal	Centrally located; can be mildly expansile	Many techniques have been described, recurrence is common
	Single chamber versus multiloculated with septa	Radiolucent	Aspiration and injection with steroids
	Contain serous fluid	"Fallen fragment sign"	Curettage/bone graft
	Active if adjacent to the physis, latent if >0.5 cm from physis	Risk of fracture increased if diameter of cyst >85% or cyst wall <5 mm width	Decompress into medullary space with rush pin or others
Aneurysmal bone cyst	Benign but aggressive	Metaphyseal, eccentric, or central	Highly vascular
	Spongelike collection of fibrous tissue, blood	Expansile, osteolytic	Simple curettage and bone grafting have high recurrence
	Destructive, elevates periosteum, but maintains thin osseous shell	Pathologic fracture heals, but ABC will persist and enlarge – recurrent fracture	Extensive curettage, bone grafting for larger lesions
Fibrous cortical defect (FCD)	Common in children	Metaphyseal	Observation, most regress spontaneously
	Distal femur or proximal tibia most common	Eccentric with thinned cortex	
		1–2 cm	
Non-ossifying fibroma (NOF)	Same as FCD, but >5 cm	Metaphyseal	Treat pathologic fracture
	Multiple in one third	Eccentric, radiolucent	Occasionally consider surgery for large lesions (>50% width of bone) which are painful or have refractured
	Regress spontaneously	Uniloculated or multiloculated	Curettage and bone grafting
		Healing normal after fracture	
Fibrous dysplasia	Fibrous tissue proliferation in medullary canal	Lytic, "ground-glass" appearance	Observation unless fractures or progressive bony deformities
	One or more sites may have diffuse involvement	Cortex may be thinned by endosteal erosion	Recurrence common
Osteoid osteoma	Night pain	Sclerotic reaction, central nidus	Surgical excision if chronic or severe symptoms and lesion is accessible
	Relief with aspirin or NSAIDs	CT scan helpful	
	Natural history is resolution		
Osteoblastoma	Similar pathology to osteoid osteoma	Lytic lesion often with a sclerotic rim	Observe if asymptomatic
	Benign but aggressive	Expansile, >2 cm	Resect if symptomatic
		Posterior elements of spine, numerous other sites	
Osteochondroma	Lump around the knee, shoulder, or ankle	Metaphyseal	Remove if symptomatic
	Multiple hereditary form	Eccentric	Remove in adults if painful or growing (risk of malignant transformation)
	Grow in proportion to the growth of the child	Bony base with cartilaginous cap	
	May occur in spine	"Sessile" (flat, smooth) versus "pedunculated" (has a stalk)	
Enchondroma	Hands most common	Punctuate calcifications within lesions	Biopsy
	Usually not painful	May be expansile	Radiographic follow-up to confirm no growth
			Curettage if large and/or symptomatic
Langerhans cell histiocytosis	Wide variety of presentation	Radiolucent lesion of vertebral body, ilium, or long bone	Natural history is for improvement
	School-aged children for isolated LCH	"Punched out" at first, then periosteal reaction	Biopsy
	Look for multiple lesions		Chemotherapy only for disseminated/fulminant disease

Fig. 42.3 Examples of benign tumors include (**a**) unicameral bone cyst, (**b**) non-ossifying fibroma, (**c**) osteochondroma, (**d**) osteoblastoma, (**e**) fibrous dysplasia, and (**f**) enchondroma

Fig. 42.3 (continued)

Treatment of Malignant Bone Tumors

When resources for comprehensive care are unavailable, it is often more practical to definitively treat a biopsy proven or clinic-radiologically diagnosed malignant lesion by radical excision or amputation. This is followed, where possible, by limited adjuvant chemotherapy. Limited resection or limb salvage procedures are rarely appropriate due to lack of capacity for reconstructive surgery and rehabilitation facilities. Where diagnostic and therapeutic resources are more abundant, proper management of both benign and malignant lesions usually requires a staged approach, and the casual volunteer should assist his national colleagues in the process, but refrain from starting what no one else will be able to finish.

Osteosarcoma is the most frequent primary bone cancer with a peak incidence in the second decade and usually involving metaphyses about the knee or the proximal humerus. Radiographs demonstrate a destructive lesion with both lytic and blastic areas, cortical destruction, and reac-

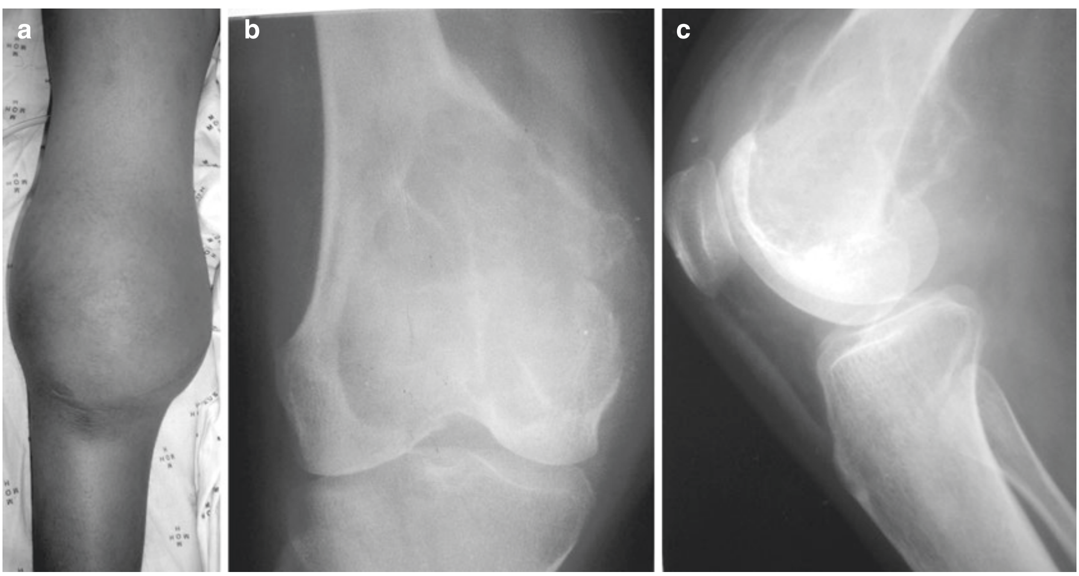

Fig. 42.4 (**a**–**c**) A giant cell tumor of the distal femur with soft tissue infiltration was (**d**) treated by curettage and bone cement. Subsequent tumor recurrence necessitated an above-knee amputation

Fig. 42.4 (continued)

tive periosteal bone at the margins. Poor prognostic factors include metastases, elevated alkaline phosphatase and lactate dehydrogenase, large tumor size, poor tumor necrosis following neoadjuvant chemotherapy, and location in the pelvis, proximal femur, or proximal humerus. A palliative amputation is sometimes offered (Fig. 42.5). Many patients are simply counseled and given limited palliative care, as the 5-year survival rate with surgery alone is only approximately 20% [3].

Ewing sarcoma belongs to the family of neuroectodermal tumors and is seen in adolescents and young adults. Approximately 50% of lesions are in the extremities. These lesions commonly present with a painful soft tissue mass and fever, and other constitutional features include weight loss and malaise. Findings on plain radiographs include diaphyseal location, "moth-eaten" or permeative pattern of destruction, and a characteristic "onion skin" periosteal response. Up to 10% may have multiple site involvement.

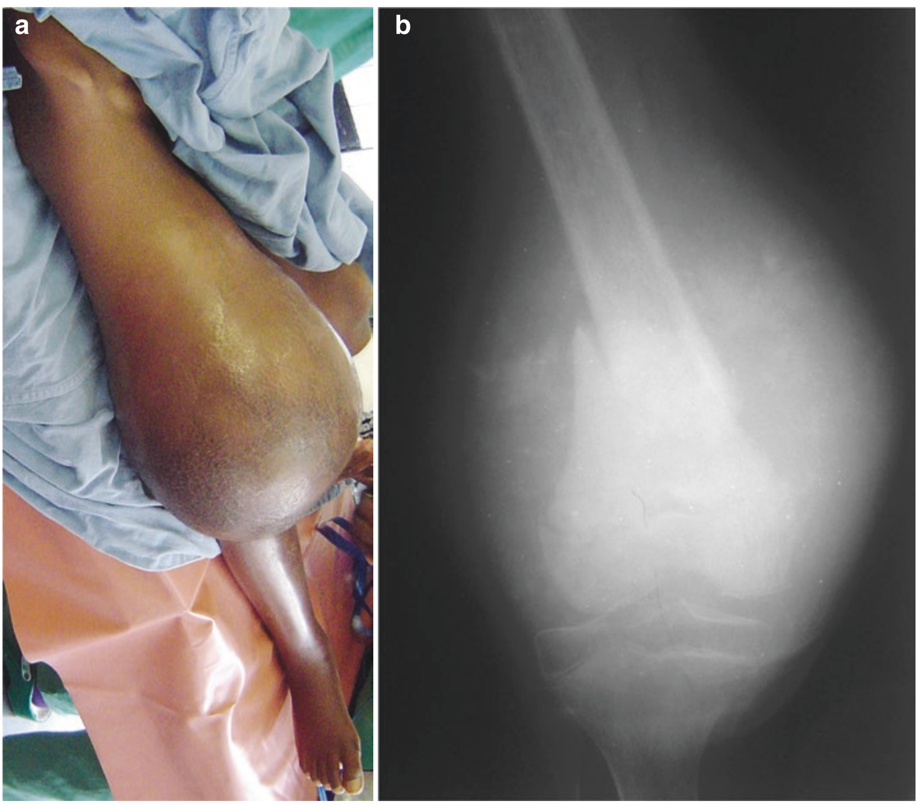

Fig. 42.5 (**a**, **b**) This osteosarcoma with pathologic fracture was treated by a (**c**) palliative hip disarticulation. Note the visible inguinal lymph nodes in photo (**a**)

Fig. 42.5 (continued)

Fig. 42.6 Recurrent chondrosarcoma of the proximal femur

Chondrosarcoma commonly presents in patients 30–60 years of age (Fig. 42.6). These lesions arise in the metadiaphyseal region of long bones or the pelvis, scapula, or ribs. Some chondrosarcomas are secondary, arising in preexisting benign lesions such as osteochondromas. Chondrosarcomas are usually managed by wide excision without the need for chemotherapy or radiotherapy.

Spindle cell sarcomas are a heterogeneous group including fibrosarcoma, malignant fibrous histiocytoma, leiomyosarcoma, and undifferentiated sarcoma. They account for 2–5% of all primary bone malignancies. Age at presentation is commonly 30–60 years with males more commonly affected. These sarcomas can arise in patients with Paget's disease or postirradiation. The treatment is similar to osteosarcoma.

Burkitts lymphoma is the most common malignant disease of children in tropical Africa and is rapidly fatal if untreated [4, 5]. These tumors are associated with the Epstein-Barr virus and have a predilection for the mandible and maxilla. Only 3–7% of cases have appendicular skeletal involvement, most commonly the femur, tibia, and humerus. The X-ray can mimic acute hematogenous osteomyelitis, chronic osteomyelitis, Ewing sarcoma, osteogenic sarcoma, acute leukemia, or congenital syphilis (Fig. 42.7). Most patients are under 10 years and have limited pain, tenderness, or local inflammation without regional lymphadenopathy, normal white cell count, and no systemic signs or symptoms. The tumor presents as a rapidly growing mass, and typical sites of involvement are the jaw, abdomen, and pelvis. The diagnosis is confirmed by fine needle aspiration or open biopsy. The tumor responds well to cytotoxic drugs.

Fig. 42.7 Burkitts lymphoma can mimic chronic osteomyelitis

The role of surgery in Burkitts lymphoma is limited to biopsy and rarely abdominal tumor debulking to improve the response to chemotherapy. Skeletal lesions, including pathologic fractures, usually heal without special treatment. Patients may present with paraplegia due to cord compression by extradural tumor deposits arising from a vertebral, retroperitoneal, or posterior mediastinal tumor mass or cord ischemia. The paraplegia due to Burkitts tumor is usually flaccid, is not associated with a kyphosis, and rarely involves the vertebral body or intervertebral disc.

Treatment of Soft Tissue Tumors

Primary soft tissue tumors are rare, and there are numerous diagnoses, many of which have a spectrum of biologic potential. Factors suggestive of malignancy include size >5 cm, rapid increase in size, location deep to the fascia, nonmechanical pain, recurrence after previous excision, and evidence of bony involvement with lysis, new bone formation, and periosteal elevation. All high-risk lesions should be referred to the highest level of service possible and lesions with a low risk of malignancy can be treated by excisional biopsy.

Treatment of Metastatic Tumors

Pain due to impending or completed pathologic fracture is often the reason for consultation leading to the diagnosis of metastatic disease. Osteolytic metastases due to breast, lung, thyroid, kidney, or other primary cancers are common, as populations in LMICs are aging and tobacco use increasing. The goal of palliative care is to keep the patient pain free and functional for as long as possible. It is generally agreed that painful lesions eroding more than 50% of the cortex in both planes should undergo prophylactic internal fixation. Without adjuvant therapies, the disease will inevitably progress, so fixation should be as robust as possible.

After a fracture has occurred, open fixation is required. Unless methyl methacrylate is available, the best approach is curettage of the tumor and internal fixation with a nail, single or double plating, or preferably both, using small screws and cerclage wire. Such constructs do not aim at bone healing, but rather at outlasting the patient before failure. Blood should always be available for transfusion and a pneumatic tourniquet used. A proximal disarticulation is a last option that few patients are willing to accept, especially when they understand the severity of their prognosis.

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Amputations

43

Richard A. Gosselin and Douglas G. Smith

Introduction

In low- and middle-income countries (LMICs), amputation for tumors, trauma, infections, and chronic diseases is a common surgical procedure and often remains the best or only option as limb salvage is rarely feasible [1]. Surgeons working in low-resource environments must therefore be very comfortable with a variety of amputation techniques [2].

Amputation surgery is a process—not just a procedure—and needs to address the gamut of physical, psychological, social, and rehabilitation issues affecting the patient and his or her family. Amputation surgery has two separate goals: removal of the disease or injured part and reconstruction of the residual limb. Whereas the first goal rests on the surgeon's shoulders, the second requires a team of professionals, which will rarely be present in full. Ideally, the surgeon works pre- and postoperatively with the prosthetist and prosthetic technician who provide expertise on the fabrication and maintenance of the prosthesis and the physiotherapist or occupational therapist who trains the patient in optimal use of the prosthesis and activities of daily living.

The surgeon needs to be aware of the extent of available resources, expertise, and technologies, keeping in mind sustainability for the patient.

General Principles

The ideal upper extremity (UE) stump preserves as much distal function as possible as severely limited hand function is still better than having no hand. The stump should be painless, sensate, and without wounds, with the ability to provide assistive function as a paddle or claw. In LMICs the majority of patients manage with only their UE stumps, using a prosthetic hand only for cosmesis.

The ideal lower extremity (LE) stump is painless, end-bearing, well padded, and balanced. A good prosthetic fitting ensures relatively equal leg lengths, with preservation of pelvic and spinal alignment for minimum energy expenditure dur-

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ing gait. Comorbidities such as malnutrition, anemia, or diabetes are common, must be considered, and can lead to wound healing problems.

Seldom is the need for a formal amputation an emergency. If at all possible when contemplating the possible need for an amputation, evaluate the extremity with a colleague before and after a debridement or during a second trip to the OR. Pictures help, especially with an intercalary injury when the toes or fingers may still be present and even have a flicker of motion that is demonstrable outside the dressing, but the limb is not functional. An informed and properly translated consent, signed by the patient or the decision maker, needs to be obtained, even in lifesaving situations, as some societies consider death preferable to amputation. Such decisions must be respected, even if the surgeon sees an amputation as a solution.

Once the decision to amputate is agreed, the surgeon should aim for the most distal level that removes the disease and is compatible with sound wound healing and prosthetic fitting. Contrary to military wounds (see Chap. 44), where amputation surgery should err on the aggressive side of debridement, the surgeon facing a mangled extremity from a civilian injury should err on the conservative side, leaving questionable tissue intact with both the patient and surgeon prepared to remove more tissue or shorten the stump at the next surgical setting. Amputations for chronic conditions, particularly in dysvascular patients, should be at a level that provides the best chance of healing. As the prevalence of diabetes is increasing worldwide, amputations for "wet gangrene" will be more common [3]. Amputation in such conditions should almost never be closed primarily [4]. In tumor or dysvascular amputations, an initial more proximal level might be easier for a patient to accept than taking a chance at a more distal level that would lead to later revision, disappointment, and prolonged hospitalization.

If at all possible children's amputations should be done through the joint rather than above, preserving valuable longitudinal growth potential. This is especially applicable when contemplating an above-knee amputation with loss of the distal femoral physis. Though split skin grafts (SSG) are not ideal, if in trauma situations, especially if faced with a very short BKA or an AKA rather than a through knee disarticulation from loss of the skin, it may be worthwhile to try to save length or a joint through a combination of "flaps of opportunity" and SSGs. Once the scars have healed and are well mobilized, it may be possible to remove the SSG or replace it with more resilient tissue.

Skin

The ideal scar is painless, pliable, and nonadherent to underlying tissues or bone. Conventional flaps for elective amputations can be planned and marked before cutting. When faced with "flaps of opportunity" after trauma, retain as much viable soft tissue as possible during the initial debridement, and do not primarily close the wound. Delayed primary closure on the fifth day allows assessment for recontouring the flaps. Elective amputations for tumors or vascular disease can sometimes be closed primarily. However, if there is any doubt about tissue viability, leave the stump open until delayed closure at 5 days. Under no condition, close a wound under tension.

As a good blood supply is essential for stump healing, avoid subcutaneous dissection by lifting a full fasciocutaneous flap wherever possible. Flaps should be generous as it is easier to trim excess skin than shorten the bone because of insufficient coverage. A tourniquet should be used and released before closure. To our knowledge there is no evidence to support not using a tourniquet in dysvascular or sickle cell patients.

Muscles

Muscles provide padding and balance between the agonist and antagonistic groups. A transected muscle belly bleeds and swells more than a muscle severed at or near its tendinous junction, making a bulky or unbalanced stump. Muscle should be cut obliquely—longer at the edge adjacent to the skin flap to shorter as the cut nears the bone. Muscles can be stabilized over the end of the cut bone in one of four ways:

- *Myofascial* closure re-approximates the outer fascial envelope to the skin flap encasing the bone. Only the superficial layers of the muscle are involved, with the deeper layers retracting proximally, often resulting in a "cone-head" stump, which is difficult to fit and should be reserved for cases with a high risk of ischemia.
- *Myoplasty* closure is common in diaphyseal amputations, where muscle bellies are transected, leaving fascial and aponeurotic tissues unsuited for bony reattachment. Opposing muscle masses are sutured together over the bone end, providing distal padding. Unless they anchor themselves to bone with scar, they can act as an antagonistic sling, sliding over the bone end, creating a painful bursa and an unstable basis for the prosthesis.
- *Myodesis* closure anchors the deep muscle layers to the periosteum or to the bone through drill holes. The superficial muscle layers are re-approximated in a myoplasty fashion. This provides padding and balance, as deforming forces on the stump are counteracted by the myodesis. For example, an adductor myodesis of a transfemoral amputation prevents an abduction deformity from unopposed hip abductors.
- *Tenodesis* closure secures the distal tendon directly to the bone. It is the most physiologic technique, but usually feasible only in disarticulations.

Whatever the muscle closure technique, correct tensioning is important, dictated by clinical judgment. Experience suggests to err on the lax rather than the tight side.

Nerves

Many techniques have been proposed to prevent painful, postoperative neuromas and phantom pain. Phantom pain is the abnormal persistent or even worsening pain with time, as opposed to phantom sensation, which is a normal self-limited sensory phenomenon of the missing limb. None of the techniques has proved superior. A simple sharp transection under gentle traction so the nerve retracts into a well-cushioned area away from scar and prosthetic pressure remains the technique of choice. Avoid excessive traction that can cause proximal axonotmesis and residual pain.

Preserve sensory nerves supplying the stump, particularly in the upper extremity. Named nerves need to be identified and separated from their accompanying vascular bundle and not incorporated in the vascular ligature, as this can cause "pulsatile" pain. Hemostasis of a vasa nervorum is by direct compression, not electrocoagulation.

Vessels

Named arteries and veins are identified and ligated separately, with double ligation for the arteries. Small bleeders can be coagulated after release of the tourniquet and the rest managed by direct pressure before closure.

Bones

Most of the ground-to-body forces pass through the bony stump and are best distributed over the largest surface possible, making it important to avoid sharp bony prominences. Angles and corners need to be filed and rounded. The tibial stump needs to be beveled anteriorly at a 45° angle to prevent anterior skin problems. Extensive stripping of the bone should be avoided, as it can lead to irregular, painful exostoses (Fig. 43.1). In adults, the canal will eventually seal itself with scar tissue, without bone wax or canal-filling procedures. In children, bone overgrowth is a common problem prevented by capping the bone end with a periosteal flap or an osteochondral plug (See Chap. 36, Fig. 36.2).

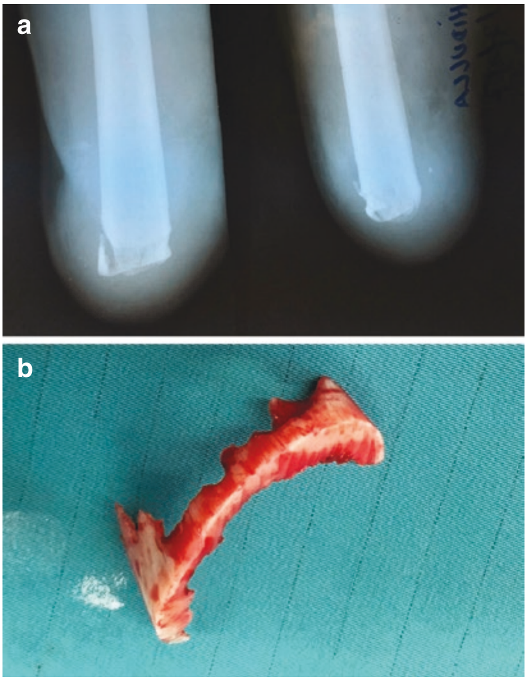

Fig. 43.1 (**a**) AKA with a draining sinus and distal sequestrum, probably from excessive stripping of periosteum. (**b**) The sequestered specimen was loose and easily removed. The stump was debrided, left open, and closed in 3 days

Wound Closure

As for all wounds, dead space should be avoided and closure achieved under physiologic tension, with excess skin trimmed as necessary to avoid dog ears but without compromising the vascularity of the flap. We recommend drains, as hematomas impair stump healing. Delayed closure should always be the case for trauma patients. It should also be the case for most infected patients such as diabetics or patients with chronic ulcers. There is no role for guillotine amputations, except in the rare lifesaving extrication situation. There is no contraindication for a split-thickness skin graft over healthy muscle of a stump. It should be as thick as possible to minimize the risk of break down (See Chap. 14 Plastics).

If the stump is closed primarily, a loose, bulky, compressive dressing is applied. The drain is removed at the first dressing change, in 24–48 h, and a new dressing applied that should be changed at suture removal (2–2.5 weeks) unless there is fever, drainage, foul odor, and increased pain—all signs of potential infection.

If the stump wound is left open at the initial surgery, it should be dressed with a bulky absorbent dressing using fluffed gauzes and light compression with elastic bandages. Do not fold back or twist the flaps while applying this dressing for fear of injuring the flap's blood supply. This dressing is only removed in the operating room at the time of delayed primary closure 4–5 days later. Subsequent management is the same as for a primarily closed stump.

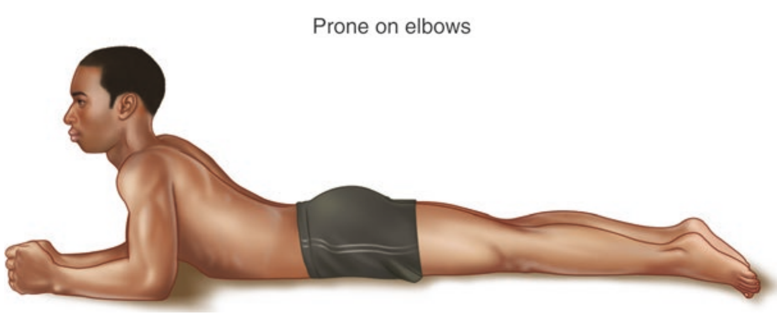

Fig. 43.2 While in the prone position, gravity combats BKA flexion contracture of the knee and AKA flexion contracture of the hip. Elbow push-ups stretch the flexors even more. Prone lying should be done twice a day for 30 min

Postoperative Management

POP back slabs for upper extremity and below-knee amputations are useful for comfort and preventing early contractures. Compressive dressings and distal elevation help control edema and pain. Avoid propping AKA stumps on pillows that lead to hip flexion contractures. For patients with BKAs, do not allow knee flexion over pillows, leading to knee flexion contractures. Patients with above-knee or through-knee amputations should spend time each day lying prone (Fig. 43.2). An active rehabilitation regimen will prevent joint contractures and stiffness, strengthen the antagonist muscles across the distal joint and proximal accessory muscles, and maximize active ROM. Adequate nutrition and cessation of smoking are important adjuncts.

After suture removal, compressive dressings with an elastic stump bandage (Fig. 43.3) will

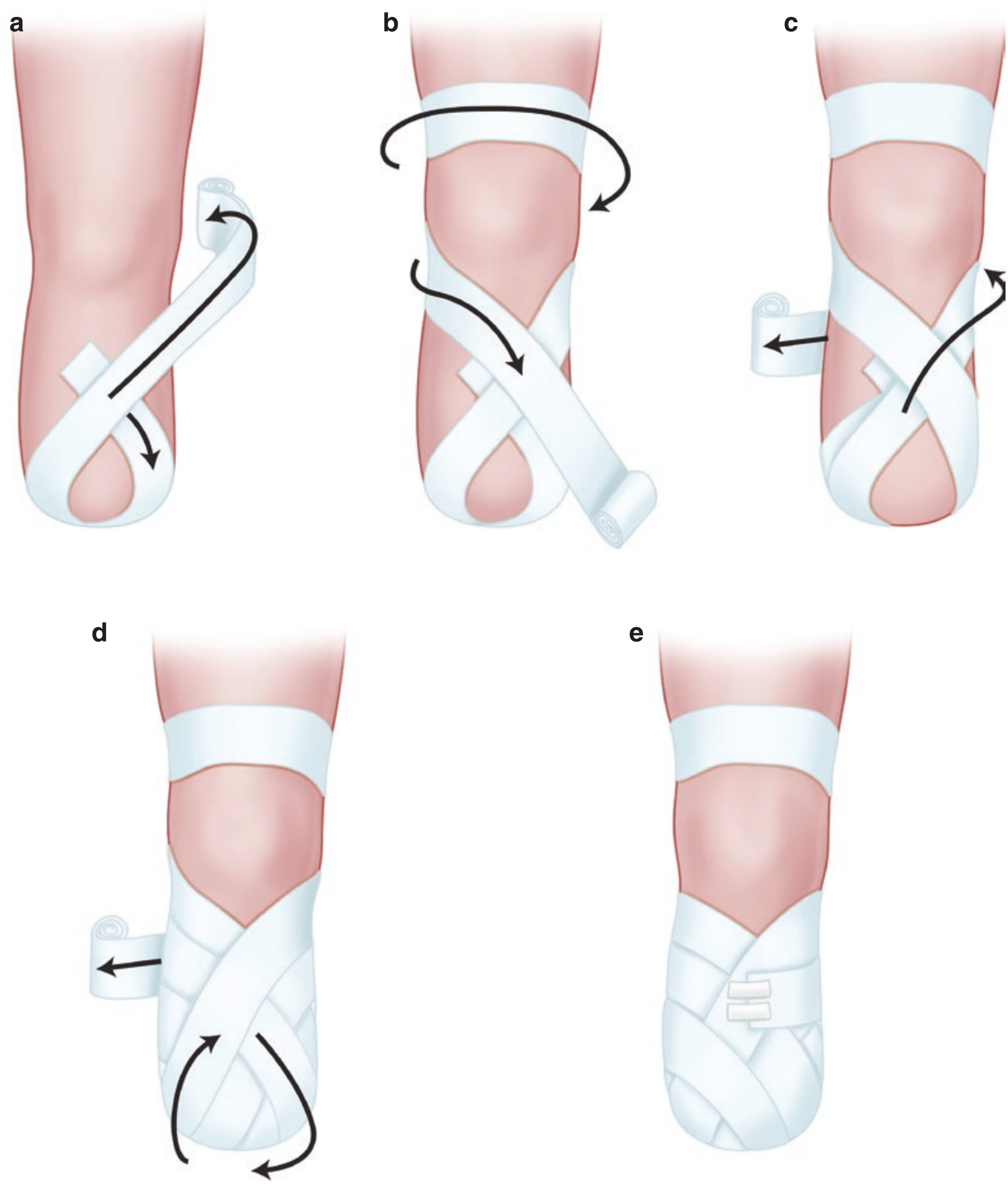

Fig. 43.3 Diagram of proper stump wrapping to promote shaping and edema control of stump

help the stump mold and mature until it is ready for the first fitting, usually around 3 months. Complete stump maturation takes around 12 months. In low-resource environments, unless in expert hands, immediate or early rigid dressings should not be used. Early temporary prostheses are rarely available.

It is beyond the scope of this chapter to address the intricacies of prosthetic technology. In low-resource environments, basic devices are usually provided by NGOs such as Handicap International, the International Committee of the Red Cross, Johanniter International, or Mercy Ships, to name the bigger organizations. Upper extremity amputees, especially when unilateral, are usually more concerned with cosmesis than function. The capacity for inexpensive 3-D printing is rapidly growing worldwide and is a potentially easy and affordable solution to prosthetic manufacture. Lower extremity amputees require a strong, durable, and comfortable prostheses for unaided ambulation. Advanced suspension systems such as osteointegrated stems may be the way to the future, but are not at present available in these settings. The amputee needs training in the daily care of his prosthesis, access to necessary supplies such as socks or stockings, instruction in the signs and symptoms of impending stump problems, and access for maintenance, repair, or replacement of the prosthesis.

An amputation is considered successful only when rehabilitation—uncomplicated wound healing, edema control, pain management, prevention of contractures and prosthetic fitting, and independence—is complete. Rehabilitation is an ongoing process, as regular prosthetic repair and replacement will be needed. An amputee is a patient for life.

Revision Amputations

Poor healing, inadequate length, contractures, wound complications, pressure sores, overgrowth, exostoses, and pain are reasons to revise an amputation. Problems usually stem from a recurrence of the disease, an incomplete initial excision, or the stump-prosthesis interface. Erosion through the skin of a poorly covered bony stump is not uncommon, particularly in BKAs when the end of the tibia is not adequately beveled (Fig. 43.4). The same principles used in primary amputation surgery apply for revision surgery with the input of the prosthetist sought whenever possible. Scarring and atrophy make revisions technically more difficult, but they should be attempted, as the difference is often between using crutches for life and using a prosthesis. If pain can be clearly demonstrated to be from a neuroma, revision surgery with a proximal sharp neurotomy can provide dramatic relief. Determining that a neuroma is the cause of the patient's pain is not easy. Tinel's test, by tapping on the precise location of pain and eliciting a sharp, lancinating pain and diagnostic blocks with local anesthetic should help confirm the diagnosis.

Skin sores, rashes, and dermatitis are not uncommon in long-term prosthetic users, especially if replacement socks are not available, are insufficiently laundered, or the patient's hygiene poor. A prosthetic holiday and return to crutch use along with local and/or systemic medical treatment are usually necessary to clear the problem.

Specific Amputations

Upper Extremity (UE) (Box 43.1)

It is important to preserve as many joints as possible in upper extremity amputations no matter how short the distal segment.

Scapulothoracic and shoulder disarticulations are mutilating procedures reserved for life-threatening situations or for "hygienic" management of chronic fungating tumors of the shoulder and proximal arm.

Above-elbow amputations should preserve as much humerus as safely possible. A stump that reaches the midline in adduction allows "paddle function." An amputation through the proximal third of the humerus is functionally the same as a shoulder disarticulation and often has an abduction contracture due to an unopposed rotator cuff. An

Fig. 43.4 (**a**, **b**) Ulceration of the skin over an ill-prepared and ill-covered tibial bony stump that was fortunately still salvageable with a proximal BKA revision

Box 43.1 General Principles for Upper Extremity Amputations

- Delayed primary closure is almost always preferable.
- Preserve some prehension capability, either by key pinch or at least side-to-side pinch.
- Stumps should be covered by sensate skin.
- When a joint has lost antagonist balance, it should be pinned in a functional position to prevent contractures and allow delayed tendon transfer or arthrodesis.
- A disarticulation is better than a more proximal trough-bone amputation. Even in adults, there is no need to remove the articular cartilage.
- A bulky hand dressing can be stabilized with volar and/or dorsal POP slabs.
- There are no indications for reimplantation.
- Assume there will be no post-op hand rehabilitation.
- Prostheses are rarely available and then only for cosmetic purposes.

amputation through the distal third of the humerus allows a myodesis of the brachialis/biceps complex to the posterior humeral cortex. The triceps can be sutured to the flexors by myoplasty.

Elbow disarticulation, after trimming the epicondyles, provides the longest lever arm in upper arm amputations and should be used, particularly in children.

Below-elbow amputations should be as long as possible to provide a sensate stump to use as a paddle, which can easily cross the midline with elbow flexion. Both bones should be cut at the same length. Proximal third amputations tend to have a supination contracture; those through the middle and distal third are more balanced. The distal half of the forearm is mostly tendinous, making padding of the bone ends difficult. Respect the sensory nervous distribution when designing the skin flaps.

The civil war in Sierra Leone revived interest in the Krukenberg procedure. It was initially described for blind bilateral forearm amputees, usually from mine blast injuries. The sensate two-prong claw has no active pinch capacity, but the preservation of active pronation-supination, combined with shoulder abduction and rotation, allows better function than a simple paddle. This technique is demanding, reserved for bilateral amputees, doing one side at a time—the non-dominant first—and the second only if the patient is satisfied with the first.

A disarticulation through the radiocarpal joint, preferably with a volar skin flap, is a good procedure, particularly in the pediatric population. Unless some rays are to be preserved, there is no benefit in retaining any of the carpal bones. The radial and ulnar styloids should be contoured to create a rounded, symmetrical stump.

Hand amputations. Initial debridement of industrial or agricultural wounds should be as conservative as possible, as many of these injuries appear more extensive on initial presentation than they are when properly evaluated in the OR. Tissues of questionable viability should be retained and left to declare themselves. They can be addressed at a second look, 48–72 h post-injury. Retain as many joints as possible as even a short sensate stub is more functional than a more proximal amputation. Immobilizing metacarpal and phalangeal fractures with K-wires stabilizes the bony architecture in the best functional position and promotes soft tissue healing.

Hand amputations for chronic conditions are done according to established techniques, such as ray resection (Fig. 43.5). Primary or delayed primary closure using sensate skin without suture tension is preferable, but temporary flap coverage or split- or full-thickness skin grafting should be attempted if it allows preservation of more length or function.

Lower Extremity (LE)

The main goal for a LE amputation is to provide a well-healed stump that allows pain-free prosthetic use without the need for walking aids.

Hindquarter amputation and hip disarticulation are reserved as heroic lifesaving maneuvers in severe open pelvic trauma, life-threatening infection (gas gangrene), or tumors.

Above-knee amputation (AKA). As a general rule, longer femoral stumps serve better than short ones. Whenever feasible, proximal one-third of amputations should leave at least 10 cm of the bone below the lesser trochanter. Shorter stumps are almost impossible to fit with a prosthesis and develop a flexion/abduction contracture from muscular imbalance.

The conventional AKA is made at the junction of the middle and distal thirds, using a classic asymmetrical fishmouth incision (Fig. 43.6). The apex of the anterior flap lies 8–10 cm distal to the proposed bone cut and is 2–3 cm longer than the posterior flap, so that the scar is slightly posterior to the end of the stump. The femoral artery is doubly ligated near Hunter's canal and the femoral vein ligated separately. The adductor magnus belly can be developed and myodesed to the lateral side of the rounded femoral bone stump. This counteracts the unopposed pull of the intact abductors on the greater trochanter. The quadriceps is cut obliquely in the coronal plane, and the available quadriceps tendon is myodesed or myoplastied posteriorly over the adductor, providing a well-padded and balanced stump (Fig. 43.7). The tourniquet is released, hemostasis secured, and the skin closed without tension over a drain (https://www.youtube.com/watch?v=QywDCl LegMA).

Knee disarticulation. Before considering this procedure in adult patients who are likely to receive a prosthesis, the surgeon needs to be absolutely sure that the skills and technology for

Fig. 43.5 (**a**) X-ray of the right hand after shotgun injury and irreparable damage to ring finger. (**b**) Dorsal view of hand after suture removal showing fillet flap of preserved volar tissue used to cover dorsum. (**c**, **d**) Hand at 1 year with full flexion and extension and satisfactory appearance

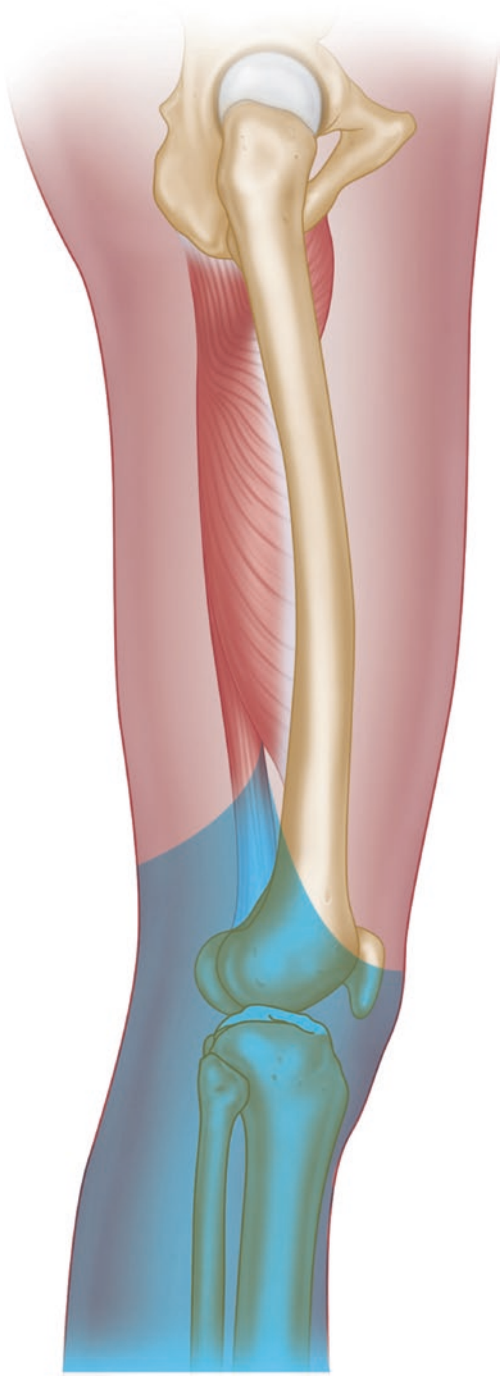

Fig. 43.6 A classic AKA starts with an asymmetrical fishmouth incision with the apex of the anterior flap 8–10 cm distal to the proposed bone cut and 2–3 cm longer than the posterior flap, so the scar is slightly posterior. The bone cut is just above Hunter's canal, where the bone starts to flare

this type of prosthesis are available. If not, a low AKA should be done. A symmetric fishmouth incision with equal medial and lateral flaps with apex just below the joint line can be used (Fig. 43.8) Alternatively, an asymmetric fishmouth can be done, with the anterior flap at or just above the joint line and the longer posterior flap at mid-gastrocnemii level. The patellar tendon is cut at the tibial tuberosity leaving the patella and will later be sutured to the PCL remnant. The joint is disarticulated from front to back, eventually reaching the popliteal vascular bundle. Artery and vein are ligated separately. After suturing the patellar tendon, the gastrocnemius bellies are sutured anteriorly, preferably using a myodesis technique. The wound is closed without removing articular cartilage or trimming the epicondyles (https://www.youtube.com/watch?v=tz4Ce5HY91o). In patients who will not walk, a knee disarticulation can have advantages in better sitting support and an improved lever arm for transfers.

Below-knee amputation (*BKA*) is the most common amputation and in austere settings is usually done because of trauma. If properly performed and the stump adequately fitted, the patient can retain a high level of function even with a low-tech prosthesis.

The level of the tibial cut is often dictated by the injury, but when done as an elective procedure, it is placed near the junction of the proximal and middle thirds, about 15 cm distal to the tuberosity or 2.5 cm for each 30 cm of patient height. Shorter stumps are more difficult to fit, and anything less than 5–6 cm tibial length is not functional. Amputations through the middle third are easy to fit, but there is no benefit to those in the distal third where good padding is difficult to achieve.

The Burgess "step" incision with a long, well-padded posterior flap remains the classic approach, although more unconventional fishmouth flaps, when properly designed, are also successful (Fig. 43.9). In the Burgess approach, the anterior skin incision lies 1–2 cm distal to the proposed bone cut and the posterior incision around 10 cm more distally to the anterior skin incision. The anterior and anterolateral compartments do not provide much padding and can be

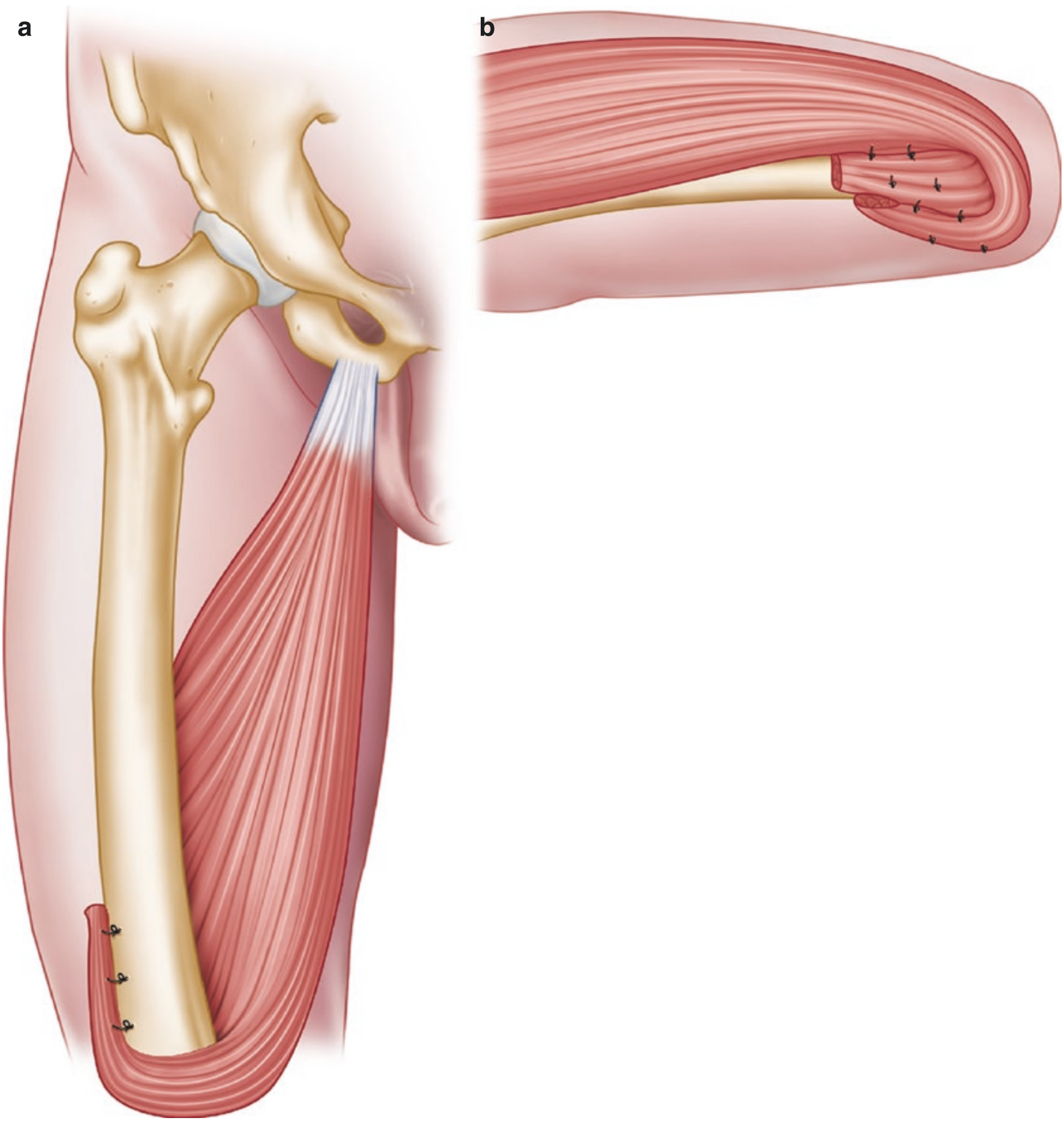

Fig. 43.7 (**a**) Myodesis of adductor magnus to the lateral femoral cortex using drill holes. (**b**) Myodesis of the quadriceps over the end of the stump and the adductor magnus over the end to attach to the linea aspera posteriorly

excised generously. The anterior tibialis neurovascular bundle is identified in the process and addressed accordingly. The saphenous vein is ligated.

The tibia is cut with a Gigli saw, incorporating a 45° anterior bevel starting at the mid-bone. This is essential. The fibula is cut 1.5–2 cm proximal to the tibia, and both bones should be filed and rounded. An excessively long fibula creates wound and prosthetic fitting complications (Fig. 43.10). The distal tibia is flexed at the osteotomy, allowing the posterior muscle mass to be cut obliquely in line with the posterior incision, completing the amputation. The posterior tibialis neurovascular bundle is identified in the process and ligated. In very short stumps, it is advisable to fix the fibula to the tibia with a screw to prevent "chopsticking," but we have seen no benefit from creating a tibiofibular synostosis (Ertl procedure) in regular stumps.

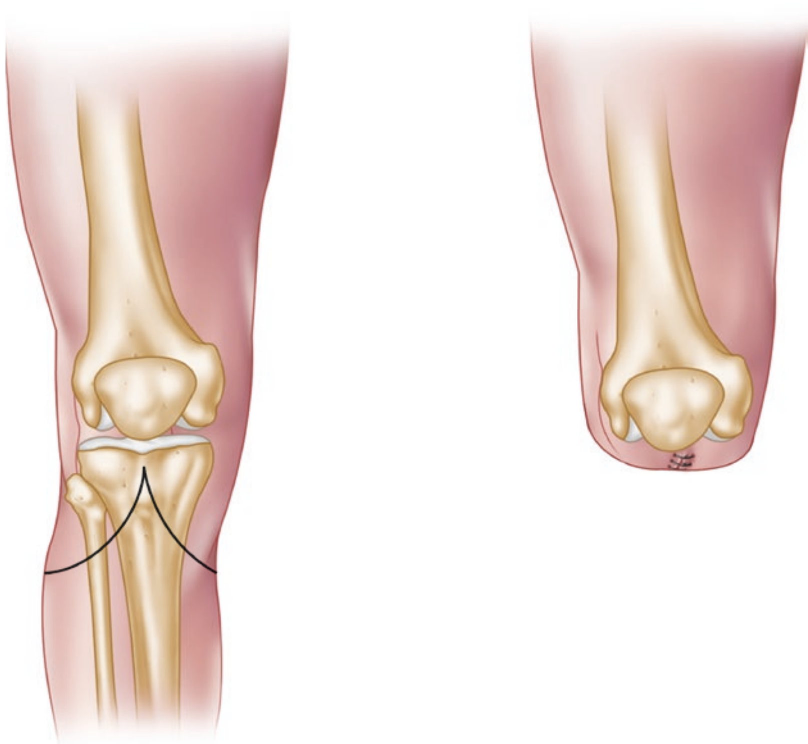

Fig. 43.8 Incision for elective knee disarticulation

Stable padding is assured by a myodesis of the posterior muscle mass through drill holes in the anterior tibial cortex or sutures in the periosteum. If the flap is too bulky, the soleus can be sacrificed. Primary closure is done without tension over a drain. The stump is immobilized in extension with a bulky dressing and posterior back slab. For trauma or any concerns about tissue health, leave the wound open, apply an absorbent bulky dressing, and return in 4 or 5 days for a delayed primary closure. When the BK stump is left open, make sure any long flaps are properly tucked within the dressing in their proper orientation and not folded back, in which case the blood supply can be compromised and the flaps lost (https://www.youtube.com/watch?v=GnXTOxFsld8).

Ankle disarticulations. The Syme procedure provides an end-bearing stump if care is taken to preserve the fragile heel pad circulation arising from the posterior tibialis artery. It is less useful in trauma because a traumatized heel pad does not provide a pain-free distal end. A wide fishmouth incision is made so that the shorter horizontal anterior limb meets the longer vertical posterior limb at the malleoli. The anterior tibial bundle is ligated, and the hindfoot bones are dissected from the heel pad, cutting from front to back and staying close to the bone around the os calcis to minimize damage to the heel pad and its blood supply. The malleoli are removed at the level of the joint and can be trimmed obliquely to decrease their bulk. The heel pad is anchored to the distal tibia through drill holes. Any doubts about soft tissue viability should delay closure until a second look in 4–5 days. The healed stump can be easily fitted with a prosthesis with a high level of function.

The Boyd procedure is beneficial in environments with limited resources, particularly in young trauma patients with good blood supply. The talus is excised, but the os calcis is retained and fused to the distal tibia in a calcaneus position with one or two retrograde Steinmann pins. A percutaneous tenotomy of the Achilles tendon will remove the deforming

Fig. 43.9 (**a**, **b**) Classic incision for "Burgess-type" BKA. (**c**) Distal fish-mouth incision, with bone cut proximal to the most proximal apex of the incision

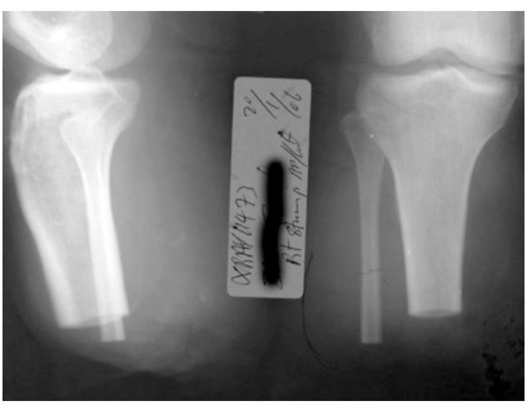

Fig. 43.10 The fibular stump is too long and needs to be revised to be 1.5–2 cm shorter than the tibia

force until the fusion is solid. The stump is protected in a non-weight-bearing below-knee POP for 3 months, after which the pins are removed and progressive weight-bearing started if x-rays show consolidation. Inconclusive x-rays require additional casting. This gives an end-bearing stump with very little leg-length discrepancy and many patients can do without a prosthesis.

A Chopart disarticulation at the talonavicular and calcaneocuboid joints is rarely indicated. The authors prefer the Boyd technique with more predictable results and fewer late complications (Fig. 43.11).

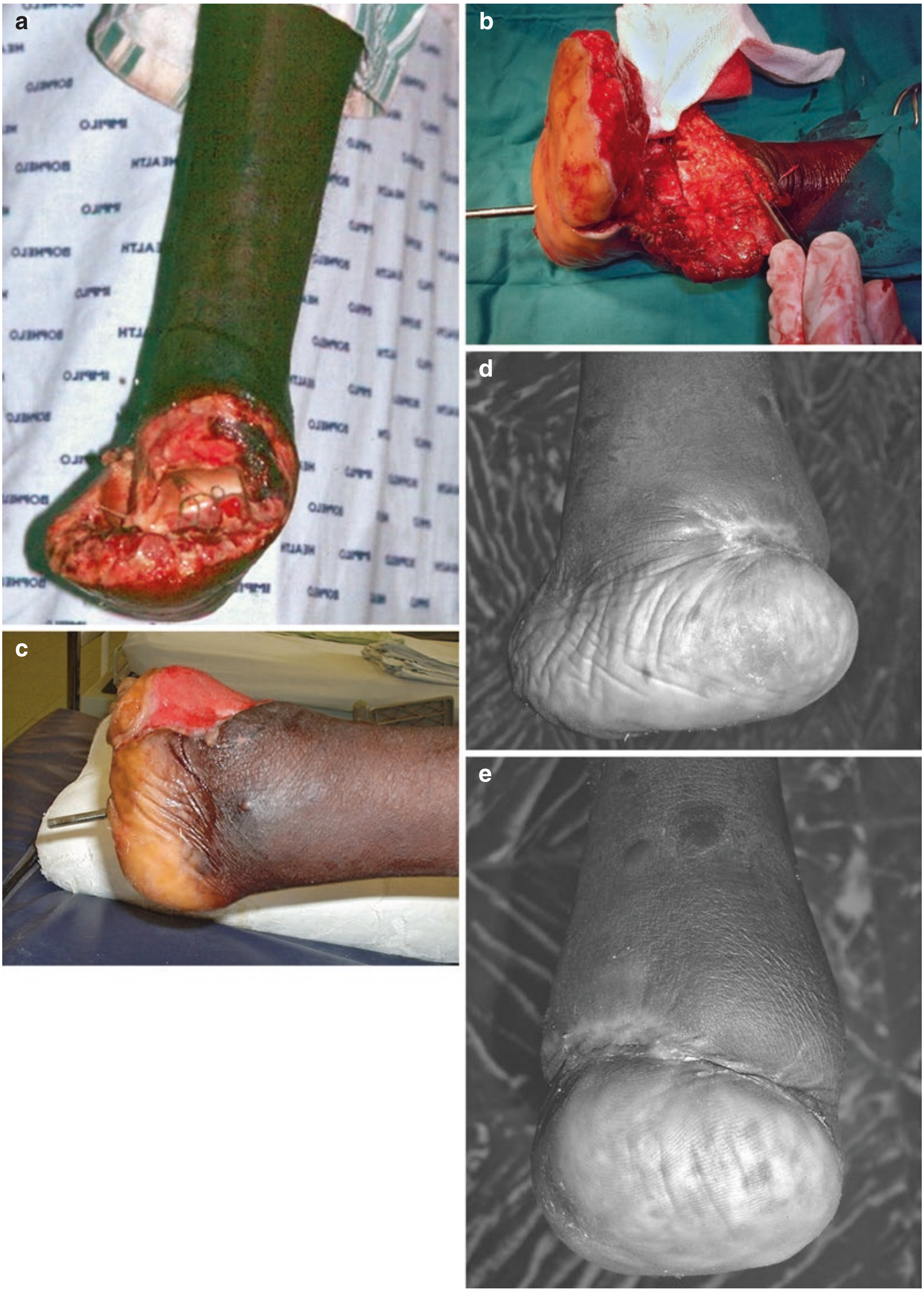

Fig. 43.11 (**a**) Appearance of the open stump after initial debridement of a traumatic amputation. The dome of the talus is visible. (**b**) Repeat DBR at 5 days, at which time a talectomy was done, tibial and calcaneal articular surfaces removed, and calcaneus fixed to tibia with one stout retrograde Steinmann pin. The Achilles tendon was transected and the wound partially closed. (**c**) The rest of the wound is granulating nicely without infection. (**d**, **e**) Clinical and (**f**) radiological appearance of the stump 6 months later. The pin was removed at 3 months, and the patient ambulated in a BK POP for 6 weeks more. He was now full weight-bearing without pain or complaints of shortening

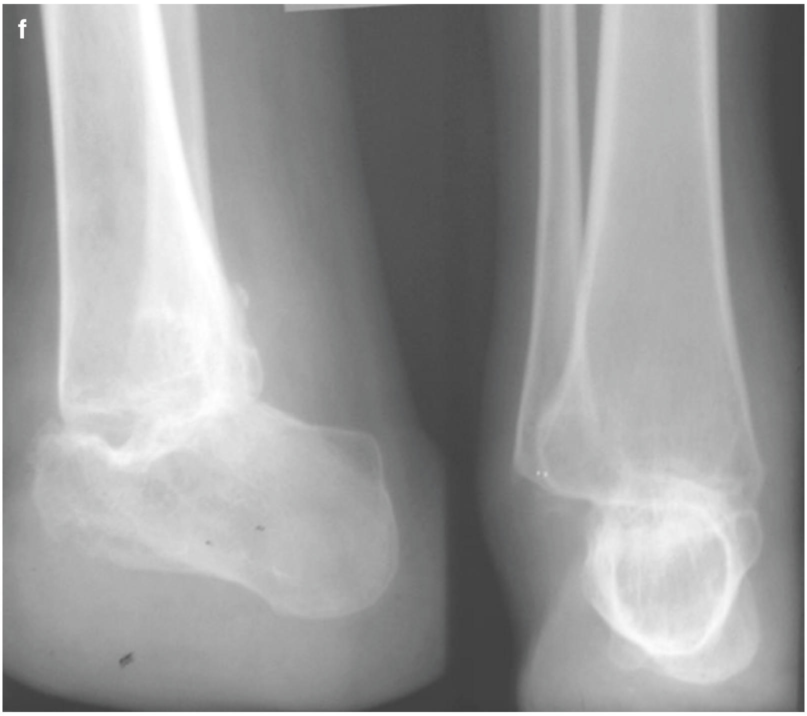

Fig. 43.11 (continued)

Foot Amputations

- Disarticulation or amputation in the midfoot is little used. Equinus deformity is common, making anterior tenodesis or Achilles tenotomy necessary.
- Transmetatarsal amputation may be indicated for multifocal osteomyelitis in diabetics or in crush injuries of the forefoot in younger patients. Prostheses are not necessary, but rebalancing by release of the Achilles tendon and stabilization of the anterior tendons should be performed.
- Ray resection may be indicated for chronic metatarsal osteomyelitis, tumor, or trauma. Delayed primary closure or closure by second intention can be effective if proper wound management resources are available. Transfer metatarsalgia is a common late complaint.
- Toe amputations or metatarsophalangeal disarticulations give very little functional disability, except for such procedures of the first ray, which may weaken push-off.

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44 Orthopedics in Conflicts and Natural Disasters

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Orthopedics in Conflicts

Introduction

Wounded military personnel of national armed forces are managed successfully by military surgeons, according to well-established protocols, along with significant logistic and medical resources. The same is rarely true for civilian victims or the members of less structured armies. In the cross-border and civil wars of the developing world, the distinction between combatants and noncombatants is blurred, and civilian casualties far outnumber military ones. Civilian orthopedic surgical practice in a conflict area is characterized by a lack of resources and a high proportion of ballistic trauma, alongside more conventional wounds.

Surgery was born on the battlefield, and two problems were critical for military leaders: control of communicable diseases and treatment of wounded combatants. Every major war has "rediscovered" surgical lessons that had been forgotten or dismissed by the generation of surgeons practicing since the previous conflict [1, 2]. However, the systematic and thorough debridement of wounds, the principle of leaving wounds open, and the judicious use of blood products are some of the lessons that have been translated from the specialized body of war surgery to present-day surgical standards [3, 4].

The psychological impact of war—whether the individual sustains an injury, is a bystander, or perpetrates the injury—must be emphasized. Disorders such as post-traumatic stress disorder (PTSD) and psychoses require early diagnosis and appropriate treatment to lessen or avert long-term disability or suicide [5].

Gunshot Wounds

The frequency of gunshot injuries depends on the presence of conflict or civil strife, tribes or groups with a history of gun culture, and gun possession laws. Victims often know their assailants, and local medical staff are often aware of the level of

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strife in specific neighborhoods and the weapons commonly used. Security forces—police, army, and civil patrol—are often involved and sometimes, for political reasons, are not cooperative. In many war-torn countries, high-velocity firearms are inexpensive and available on the open market.

Discounting combat or gang violence, most injuries are from low- to medium-velocity firearms, and wound size does not predict the extent of internal damage. X-rays can help determine the energy imparted to the bone and reveal retained missile parts and the scatter pattern of shotgun pellets. These wounds need a thorough debridement to remove casing and the priming materials (Fig. 44.1).

The extent and nature of injury from any GSW is determined by the speed of the bullet at impact, mass of the missile, size and shape of the projectile, and characteristics of the tissues through which it travels. Ballistic injuries obey the fundamental principle of $E = mv^2$ so that the velocity of the projectile matters more than its mass. High-velocity missiles not only cut and crush tissues but also produce sonic waves with cavitation effects that produce microscopic damage at a distance from the bullet path. High-velocity gunshot wounds need to be addressed by the protocols of war injury treatment [6].

Blast Injuries

The tissue damage from blast injuries (bombs, land mines) depends on the type of munitions, distance from the target, and environment in which they detonate, such as open space, inside a building, or underwater. The explosion causes injury in four ways [7, 8]:

- *Primary injury* is caused by the blast wave. All persons within the lethal zone die, while those outside it may sustain severe, non-penetrating injuries. Air-containing viscera are particularly sensitive to the damaging effects of the blast.
- *Secondary injury* is due to the direct effects of shrapnel or objects that become energized from the blast. Modern military munitions produce metallic fragments within a specific

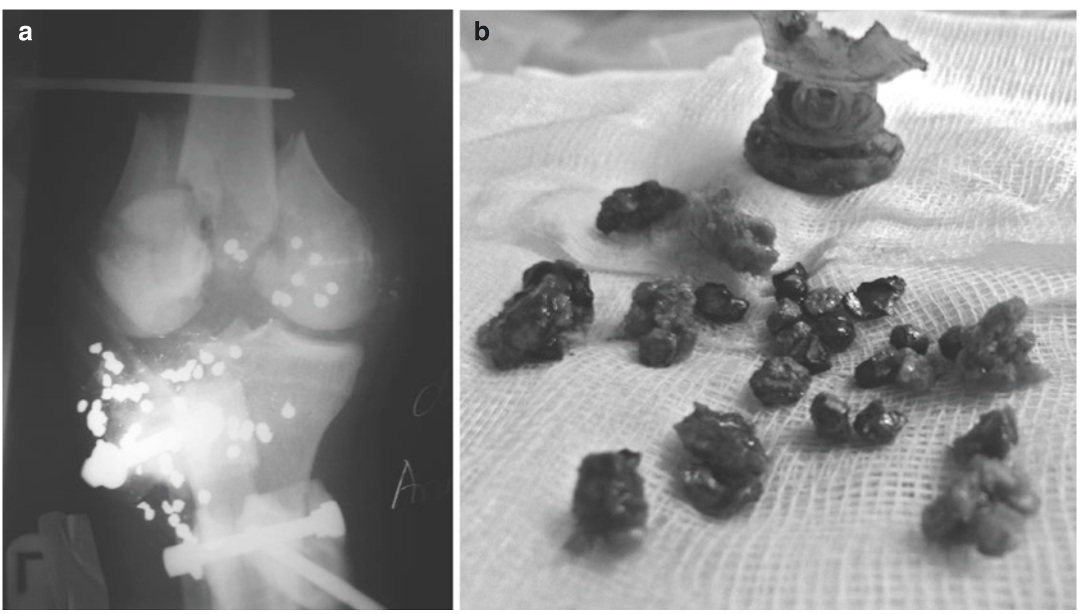

Fig. 44.1 (**a**) X-ray of GSW of the knee and (**b**) metal pellets and plastic casing retrieved only after the second debridement because of insufficient initial incisions. (Courtesy of Tomoaki Atsumi, MD)

mass range to ensure consistent and effective damage over a large area.

- *Tertiary injury* from the blast wind can project human bodies against objects or propel objects that hit humans. The wave can collapse buildings, resulting in crush injuries.
- Q*uaternary mechanism* or *flash injury* refers to the thermal wave, causing burns and inhalational injuries from smoke, including carbon monoxide.

Beyond these conventionally recognized mechanisms of blast injuries, biological contamination may take place purposely, such as a suicide bomber infected by hepatitis or HIV or by chance, if infected victims' parts contaminate survivors. Barrel bombs, such as presently used in the Syrian conflict, are often loaded with human or animal feces with the hope of contaminating survivors' wounds. Diethylenetriamine (DETA) sheet explosives contain pentaerythritol tetranitrate (PETN), which can cause a hyper-inflammatory syndrome.

Land Mines

Land mines are not designed to kill but rather to maim and destroy livelihoods. The majority of victims are civilians, and the toll is especially heavy among rural peasant farmers, nomads, livestock, children, and the poor who have little political voice. Despite huge efforts, clearing existing mines appears to be nearly impossible. Blast mines create damage through the blast wave, while fragmentation mines cause harm through propelled fragments.

Their clinicopathological effects have been grouped by ICRC into three patterns [4]. *Pattern 1* occurs when the victim steps on the mine, resulting in a traumatic amputation of some part of the triggering lower limb and variable degrees of penetrating injuries and burns to the other leg, genitalia, and body. This pattern produces the "umbrella effect" [4], in which the blast strips the soft tissue attachments from the tibia so they are spread apart as in opening an umbrella (Fig. 44.2). The soft tissue damage extends more proximally than the level of bone injury.

Pattern 2 occurs when the victim activates a fragmentation mine, spreading metallic fragments that randomly penetrate parts of the body. *Pattern 3* occurs when the victim manipulates the mine, usually children or de-miners, resulting in injuries to the upper limbs, face, neck, and chest. More powerful mines are used to neutralize motorized vehicles (anti-tank mines, improvised explosive devices, etc.) and create a wide spectrum of injuries depending on location (inside vehicle or bystander) and distance from blast.

It is beyond the scope of this chapter to discuss injuries due to chemical, bacteriological or nuclear warfare.

Surgical Epidemiology of Conflicts

Generally, in conventional artillery warfare, guerrilla warfare, and civil conflicts, the distribution of injuries includes superficial injuries requiring no hospitalization (40%) and those requiring hospitalization (60%). Sixty percent of those hospitalized will have limb injuries. The longer the delay to reach medical care, the more limb injury rates increase, as those with central wounds often die without immediate medical care. Longer delays increase the likelihood of infection. Therefore, longer delays result in more limb wounds, many with fractures, more infected wounds, more stable patients, less inhospital mortality, and more need for orthopedic surgeons. This same scenario is true for natural disasters.

A wounding mechanism frequently overlooked is road traffic injuries (RTIs). These are frequent in both conflict zones and after natural disasters, caused by disruption of road traffic control; absence of liability, especially for fighting parties not belonging to regular, disciplined armies; and vehicles and roads in a poor state of maintenance or damaged by the disaster.

Many of the following principles for treating injuries sustained in conflict situations are the same for dealing with the victims of natural disasters. The cause of the injuries may be different, and some of the ballistic-specific concerns are of less importance, but the principles are worthwhile to follow.

Fig. 44.2 (**a**) Typical land mine injury. (**b**) Umbrella effect with complete stripping of the tibia. (**c**) X-ray shows no tibial fracture

Treatment

For fresh injuries, effective treatment depends on prompt evacuation and transfer, triage of injuries, vigorous resuscitation, and aggressive exploration and debridement of wounds. Definitive management of orthopedic injuries is never considered in the initial stage (Fig. 44.3).

In urban warfare in middle-income countries, such as Iraq, transfer of the wounded to civilian hospitals can be quick and effective, and injuries are seen while still fresh. In more austere environments such as Afghanistan, Yemen, and many sub-Saharan African countries, casualties often come from a distance. In theory, the site where civilian

Fig. 44.3 (**a**, **b**) Triage tent of Emergency Hospital in Lashkargah, Afghanistan. (**c**) Patient ID tagged around the neck

Fig. 44.4 A strictly enforced "No Weapons" sign at Emergency Hospital entrance, Kabul, Afghanistan

casualties are treated should be a safe and secure haven, but this is not always the case (Fig. 44.4).

Mass Casualty Event and Triage

A mass casualty situation involves a large number of casualties presenting over a short period of time and overwhelming the facilities and resources. The general treatment principle is to "do the best for the most." This is in contrast with the civilian practice of doing the "absolute best for every individual." Triage, in a war surgery or natural disaster context, is a

Box 44.1 ICRC Triage Categories

Category 1 injuries that have a reasonable chance of survival but require resuscitation and immediate surgery

Category 2 have the second priority for surgery

Category 3 have superficial wounds and can be managed as outpatients

Category 4 involves severe wounds with a poor prognosis and given supportive care

systematic way of placing patients into four groups (Box 44.1).

Assessment and Resuscitation

Whatever the mechanism of injury, it is essential to assess the patient according to ATLS principles of primary and secondary surveys. A common pitfall is concentrating on more evident and impressive wounds, while missing a small penetrating wound in a vital area. The apparent physiologic reserve in younger patients can be misleading. They require particular attention and aggressive resuscitation with frequent reevaluations.

Land mine blast injuries in particular are associated with significant blood loss, making initial, aggressive resuscitation essential, particularly if the transfer time has been prolonged. Hemodilution will occur rapidly with crystalloid and whole blood transfusion is usually required. Family members, friends, and fellow combatants are the best donor sources. The anticipation of a large transfusion requirement may be an indication for supportive treatment only.

Wound Debridement

Limb injuries account for around 60% of all surgical injuries in conflict and natural disaster settings and are dealt with only once life-threatening injuries have been addressed. War wounds require extensive debridement, what the ICRC calls "wound excision" [4]. Adequate access is mandatory, requiring extensile skin incisions. All foreign material and necrotic tissues must be debrided [9, 10]. While only nonviable skin should be excised, subcutaneous tissue is sensitive to infection and requires generous excision. Avoid undermining the skin, which can compromise its blood supply. A fasciotomy is usually required to access deeper structures and reduce the chance of compartment syndrome. Muscle that does not appear viable must be excised based on color, absence of contractility, poor consistency, and lack of bleeding. Bone fragments without periosteal attachment should be removed no matter how large. Debridement may need to be repeated every 48–72 h until clean, viable tissue is present.

Metallic fragments located in the wound or in pressure-sensitive areas such as palms or soles deserve removal, but leave the deeply seated fragments unless they are (1) intra-articular (impinging on joint function or a potential cause of lead-induced arthropathy) or (2) close to the main vessels, where their sharp edges can erode the vessel wall and cause delayed bleeding.

All war wounds or wounds from natural disasters are contaminated and are *never* closed primarily no matter when they present or how "clean" they appear. Edema causes increased tissue pressure, leading to impaired vascularization and wound breakdown; residual contaminants and necrotic tissue left after debridement promote infection. Wounds can ideally be closed 4–7 days post debridement. Primary closure may be difficult if delayed beyond 7–10 days, at which time wound edges and flaps have retracted. However, if in doubt about the status of the wound or wound infection, a re-debridement should be performed and other plans made for closure. The routine use of a tourniquet in wound debridement has been debated, but has been promoted by the ICRC, especially in environments where blood replacement is an issue. Consider using a tourniquet in the presence of active bleeding. It can be deflated later to reassess any "doubtful" tissues before applying a bulky dressing.

Fig. 44.5 Big, bulky, absorbent dressings are applied over limb wounds or stumps

Dressings that absorb fluids, such as fluffed gauze held with a compression bandage and stabilized with a plaster slab or gutter splint, are simple and comfortable for the patient (Fig. 44.5). Extremity wounds need to be elevated using bed blocks to raise one end of the bed, pillows, or Bohler-Braun frame or supporting an arm on pillows or suspended from an IV pole. Drains are unnecessary as all extremity wounds are left open.

The ICRC protocol for wound management involves dressing removal and wound evaluation in the operating room under anesthesia at 4–7 days, followed by re-debridement and/or primary closure, skin grafting, or leaving the wound to granulate. When the expertise is available, flaps can be helpful at this stage.

Vascular Injuries

Transected named arteries are usually visible and can be ligated or repaired, but often lead to amputation. Hypotension may mask vascular injuries, and multilevel vessel injuries can occur. Cavitation damage from high-velocity missile injuries can result in intimal injury, even at a distance from the wound, leading to ischemia. A high index of suspicion and close monitoring are essential during the first few days.

Peripheral Nerve Injuries

These may involve direct laceration or contusion, but are more often due to indirect mechanisms of the blast wave or extrinsic compression. The prognosis is poor when nerve injuries are associated with vascular damage. Spinal cord injuries have a poor prognosis, even if the spine is mechanically stable, which is usually the case in ballistic injuries. Retained fragments should be removed from the spinal canal if possible.

Bones

Unless in the presence of a vascular repair, osseous injuries *never* require definitive management at initial debridement. All skeletal injuries can be treated initially with splinting or skeletal traction. External fixation can be applied at the return visit to the OR, in a sterile surgical field, and is of benefit only if it allows better wound care and early patient mobilization [10]. As soon as wound coverage is successful and stable, many external fixators can be replaced by casts. There is no indication for internal fixation in the early stages because of the high risk of infection [11]. Internal fixation may be considered for displaced intra-articular fractures in the subacute phase.

In mass casualty or natural disaster situations, contrary to usual civilian practice, the surgeon needs to err on the aggressive side of the debridement, which sometimes means amputation rather than an attempt at limb salvage. When there is no pressure on resource utilization, a more conservative approach can be taken, and repeat debridements can be considered. In such conditions, prolonged treatment, requiring multiple bone and soft tissue coverage procedures to save a limb, still might not be in the patient's best interest, and a sound amputation with a good prosthetic fitting may be the better option. Sociocultural determinants, consent issues, and availability of prosthetic services must all to be factored when deciding to amputate (Fig. 44.6).

Fig. 44.6 Typical management of a missile injury. (**a**, **b**) Anterior entry and posterior exit wound from metal fragments. (**c**) X-ray of right leg on admission. (**d**) Initial wash out with clean tap water before surgical debridement. (**e**) Devitalized bone fragments excised. (**f**) The patient post-op with ex-fix, leg elevated on frame, and heel protected. (**g**, **h**) X-ray in external fixator. (**i**) Anterior wound healed after delayed primary closure. (**j**) Posterior wound with good granulation (**k**) covered with STSG, and (**l**) the ex-fix removed and replaced with a weight-bearing POP as soon as the skin graft is mature

Fig. 44.6 (continued)

Fig. 44.6 (continued)

Natural Disasters

Introduction

Recent earthquakes in Pakistan, Iran, and Haiti have shown an unprecedented response from the international orthopedic community [12]. Tsunamis, typhoons, or hurricanes do not generate the same number or severity of orthopedic injuries. The basic principles are the same as for war injuries: management of mass casualties, organization and coordination, and "best treatment for the most" in a given environment using available resources [13]. The uniqueness of a natural disaster lies in the fact that all injuries occur within a short period of time, such that time from injury does not usually factor in management prioritization.

Stages After a Natural Disaster

The aftermath of natural disasters can be classified into five stages:

1. **Chaos**

During the first 24–48 h, no significant medical or surgical treatment is generally available other than basic first aid. The health-care system is one of the first casualties. Life-threatening injuries will sort themselves out; the others will rapidly overwhelm what is left of existing structures and the new ones set up to handle the injured.

2. **Initial Response**

Massive efforts in organization, or reorganization and coordination, are set in motion. Essential logistical components are established to provide transportation, communications, chain of command, security, power, hygiene and sanitation, water/food/shelter, and search and rescue. Medical intervention is the *last* component. It is important for a volunteer to keep a realistic perspective of where he or she fits in the overall priorities. Volunteers should not be a burden or nuisance. They should mobilize as part of a structured entity, such as government, NGO, or professional association, and not as spontaneous unaffiliated volunteers, the dreaded "SUVs." Above all, they should not tap into resources dedicated to victims.

Most of the survivors will have orthopedic injuries, but during the first 10–14 days, the problems primarily involve wound management. Other than skeletal traction, external fixation, or amputation, no formal orthopedic interventions are done at this stage. *All* wounds should be left open, and *no* internal fixation can be safely performed [14].

Skeletal traction is effective only if weights can be suspended, which is difficult if the patient is lying on the ground. External fixation is a quick way to provide temporary fixation of open fractures, their greatest benefit being access to wounds and early mobilization. There might be some indications for their use in closed pelvic or femur fractures, even if they need to be applied blindly, when early mobilization or evacuation of a patient is lifesaving. External fixation should not be viewed as the definitive treatment for the bone injury in such situations.

This is the stage where crush injuries are seen, and their management is controversial [15]. When a limb is "crushed" for more than 6 h, varying degrees of vascular compromise will be seen, depending on the amount of weight and duration of the crush (Fig. 44.7). If a limb does not reperfuse after crushing, it will require amputation. While closed injuries can often wait until

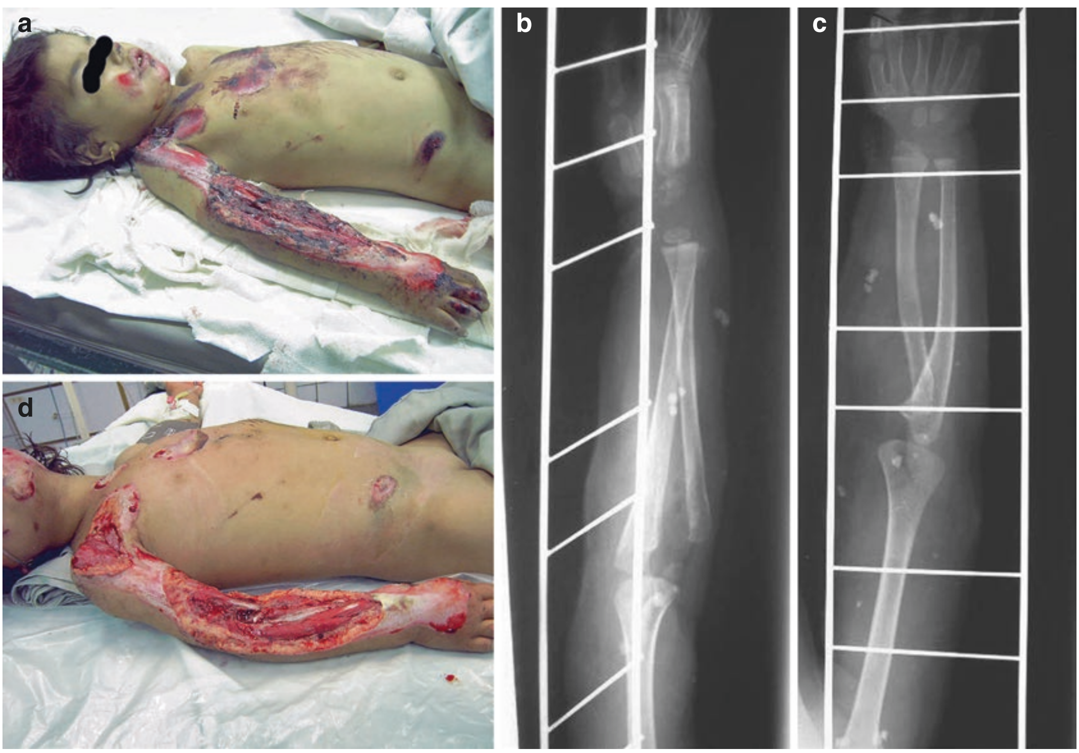

Fig. 44.7 (**a**) Child with crush injury to torso and right upper extremity before debridement. (**b**, **c**) X-ray showing proximal radial dissociation and radiodense particulate matter. (**d**) After debridement

demarcation, gangrenous limbs with open wounds require early, open amputation.

With reperfusion, toxic compounds such as potassium and cytokines are released into the circulation and may lead to systemic crush syndrome, a combination of one or more of the following: hypovolemia, hyperkalemia, sepsis, disseminated intravascular coagulation (DIC), adult respiratory distress syndrome (ARDS), renal failure, and eventually multi-organ failure and death [16]. The limb may develop compartment syndrome initially or as a result of reperfusion.

The indications for fasciotomy are also controversial. Contrary to civilian practice, almost 100% of fasciotomies for crush injuries seen late will become infected. The benefits of fasciotomy need to be carefully weighed against the risk of sepsis, the main cause of death after 5 days. The surgeon needs to first differentiate between impending and established compartment syndrome. Impending compartment syndrome usually presents within 24 h of injury. The tense compartment is painful on palpation and has pain on passive stretching, but retains some sensory, motor, or vascular function. These compartments may benefit from release to prevent further compromise.

Established compartment syndrome usually presents after 24 h, with no function in the affected limb. Fasciotomies in such patients are contraindicated as they have no functional benefit and will always lead to wound infection. The delayed management of compartment syndrome sequelae may still be better than an amputation for infected surgical wounds. Medical management of crush syndrome might be necessary, but amputating a dead limb does not decrease the systemic effects of necrotic tissue, and "prophylactic" amputation, as proposed by some, is a useless and hazardous endeavor. There is also no indication for a "guillotine" amputation, except maybe a disarticulation as a lifesaving maneuver to extirpate a trapped patient. Amputations should be done using standard flaps, or flaps of opportunity, and the wound left open, to be closed in a delayed fashion 4–7 days later, as per ICRC protocol.

3. **Definitive Management of Injuries**

After the first or second week, portable operating rooms have been deployed, some local infrastructure has been provided for "safe" surgery, laboratory and x-ray are available, and treatment can be planned. Wound management still has high priority, but at this stage, definitive closure of clean wounds is possible with skin grafts and/or flaps. Closed fractures, particularly intra-articular ones, can usually be treated safely with internal fixation.

In appropriate surgical environments, IM nailing of long bones is also feasible. In open fractures, treatment of the underlying fracture may require a "pin holiday," with or without traction, after ex-fix removal and before definitive ORIF. Open reduction is almost always necessary since more than a month has often passed since injury. Tibia fractures can often be treated by casting if alignment can be corrected by closed means such as cast wedging.

4. **Management of Complications**

This stage overlaps the previous one as early complications of some injuries, and procedures may be seen before definitive management of others is started or in progress. Infections, with or without retained hardware, are the most common complications, along with nonunions and malunions. Appropriate surgical environments offer the possibility of ORIF. Stump problems are common and may require reshaping or revision at higher levels, as discussed in Chap. 43. At this stage, stump management should be in concert with available prosthetic expertise and resources.

5. **Rehabilitation**

This stage overlaps all the previous stages, except chaos. Even in the early stages of treatment, the complex rehabilitation process needs to be kept in mind, as return to optimum function is the most important goal after life and limb are saved (see Chap. 45). Organizations such as Handicap International, ICRC, and Johanniter have extensive experience, expertise, and resources in the field of patient rehabilitation in austere environments.

The needs for system rehabilitation, including health care and education, are more difficult to define, but an opportunity to share knowledge, experience, and resources with national colleagues should never be wasted.

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Resources

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Management of limb injuries during disasters and conflicts. https://icrc.aoeducation.org/files/downloads/A_Field_Guide_Low_res.pdf.

45 Physical Rehabilitation of Orthopedic Conditions in Austere Environments

Maysa Alnattah and James E. Gosney Jr.

Introduction

This chapter addresses the general organization and delivery of physical rehabilitation in low- and middle-income countries (LMICs), particularly in natural disaster and human conflict settings. It concentrates on the general physical rehabilitation of common orthopedic injuries and provides an overview of prosthetic and orthotic care. Challenges associated with physical rehabilitation in austere environments conclude the chapter.

Rehabilitation is globally recognized as those measures that assist disabled or impaired individuals to achieve and maintain optimal function while interacting with their environments. Rehabilitation professionals including therapists, nurses, prosthetic and orthotic (P&O) specialists, and rehabilitation doctors manage physical and cognitive impairment through assessment, diagnosis, prevention of complications, and treatment to reduce impairments and optimize function. Mobility, activities of daily living training (ADL), and assessment for and provision of durable medical equipment and assistive aids are common orthopedic rehabilitation tasks. Educating and counseling patients and caregivers improves patient compliance, optimizes outcomes, reduces the care burden on families and communities, and mitigates the impact of lost productivity and income.

Barriers to effective rehabilitation include lack of technical skills, materials, funding, equipment, and rehabilitation infrastructure. Women, children, the elderly, and those with pre-existing disabilities require special attention as they face disproportionate risks. Rehabilitation is especially critical to recovery where surgery is not available. The World Health Organization (WHO) recognizes rehabilitation as an essential service.

General Organization of Rehabilitation Delivery

Rehabilitation delivery varies based on care site, service type, injury/condition being treated, and provider. Care sites in LMICs include hospitals, outpatient and community clinics, and persons' homes. Rehabilitation services comprise a range of physical interventions with material support and education and training appropriate to the injury/condition. The variation in care sites and services between and within LMICs ranges from well-resourced hospitals, outpatient, and community rehabilitation centers with full comple-

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ments of rehabilitation staff to settings with a single rehabilitation technician. Given this variability, surgical teams and surgeons must expect to provide rehabilitation.

Surgical Team Rehabilitation Planning and Coordination

Surgical teams should have advance awareness of mission rehabilitation requirements and the capability of the host facility and local area. Rehabilitation needs and capabilities assessment on arrival will confirm planning estimates, inform coordination with local partners, and guide team operations. Rehabilitation expertise should be integrated into daily medical routine, including patient triage, perioperative assessment on clinical rounds, patient/family meetings, and discharge/referral planning. Fully incorporating rehabilitation considerations into patient management provides timely discharge, improved outcomes, fewer complications, and reduced long-term disability.

Surgical Team Physical Rehabilitation Process

Following patient triage, resuscitation, and emergency surgery, a rehabilitation assessment and treatment plan are developed. The patient's general physical condition, medical status, level of function, physical and cognitive limitations, ADLs, need for mobility aids, pain management, discharge rehabilitation, and home modification are addressed. Early in the admission, a comprehensive discharge plan to include rehabilitation needs to be made. Rapid discharge is a priority in disaster and conflict situations due to high patient volume, limited bed capacity, and demand on resources. As community rehabilitation services may be lacking, unavailable, or inaccessible, rigorous home rehabilitation with family support is critical to maintain gains, prevent complications, and achieve desired outcomes.

Box 45.1 Role of Rehabilitation to Reduce Complications

1. *Malunion or deformities*: splinting or casting, observation, x-rays
2. *Infection*: regular monitoring for signs of infection – redness, swelling, discharge
3. *Deep vein thrombosis (DVT)*: bandaging or elastic stocking, lower limb exercise
4. *Lung congestion or pneumonia*: respiratory therapy
5. *Pressure ulcers and bed sores*: hourly positional changes
6. *Joint stiffness*: daily active and passive ROM exercises
7. *Muscle wasting*: daily strengthening exercise

General Rehabilitation Goals

General rehabilitation goals include restoring physical function, improving mobility, and reducing complications (See Box 45.1). Functional mobility training includes bed mobility and transfers – moving from one surface to another, such as from a bed to a chair, and ambulation – demonstrating proper gait with a cane, crutches, or walking frame and use of a wheelchair. Preventing negative secondary medical outcomes and consequences of inappropriate and neglected rehabilitation is important because complications are more common in austere environments due to lack of properly trained mission and local staff, inadequate discharge planning, and other factors.

Rehabilitation Interventions

Short-term goals include controlling inflammation and pain and improving muscle strength, range of motion (ROM) of injured and unaffected limbs, and cardiorespiratory function. Longer-term goals include maintenance of muscle strength and joint ROM gains; improved balance, coordination, and mobility; and increased independence. Basic rehabilitation interventions include exercise therapy, gait training, respiratory therapy, casting and traction, and education.

Exercise Therapy

Exercise therapy restores normal musculoskeletal function and/or reduces pain at the injury site. Therapeutic exercises are specified by frequency, duration, and intensity (number of repetitions and amount of resistance). Being intensive and repetitive, they require patient time and commitment. Exercise types are characterized in Table 45.1.

Gait Training

Gait training is necessary for independence and depends on patient pre-injury health, injury severity, rehabilitation while in bed, conditioning, strength level, and motivation. Strengthening, balance, and coordination exercises are started while the patient is still on bedrest for precondi-

Table 45.1 Summary of exercise types by definition, goal, subtype, and prescription indication

Exercise type	Definition/therapy notes	Goals	Subtypes	Prescription indication
ROM exercises	Exercises designed to move a joint through its full ROM Begin as soon as possible upon patient admission	Increase joint mobility and flexibility by affecting the joint capsule, ligaments, tendons, and muscles Preserve and maintain joint mobility Prevent joint stiffness and muscle shortening	Passive (PROM)	Patient cannot move the injured joint/limb Performed by the therapist
			Assistive	Patient can move the joint but not through its full ROM Assistance may be provided by the therapist
			Active	Patient can actively move the joint through its full ROM Therapist may help guide the joint through its ROM
Strengthening exercises	Exercises designed to produce muscular contraction to build size, strength, and anaerobic endurance of skeletal muscles Muscle contraction does not change muscle length/joint angle. Begin as soon as possible; perform at least 2–3/× daily	Increase muscle, tendon, and ligament strength Improve joint control Increase bone density Increase metabolism Improve cardiac function and general fitness	Isometric	Patient cannot move the joint (due to muscle weakness, joint fixation, casting, etc.)
			Non-resistive (active)	Limb movement with gravity (no external resistance). Number of repetitions/sets based on patient physical ability specified
			Resistive	External manual/mechanical resistance is applied Therapist may apply manual resistance by resisting patient movement Patient may apply mechanical resistance by resisting against dumbbells/weight straps/therabands (as able)
Stretching exercises	Exercises designed to stretch/expand muscles and other soft tissues surrounding a joint Begin as soon as possible; perform at least 2–3/× daily	Prevent muscle and soft tissue shortening Prevent joint stiffness and loss of ROM Decrease spasticity	Passive	Patient is bedbound Performed by the patient or therapist
			Active	

(continued)

Table 45.1 (continued)

Exercise type	Definition/therapy notes	Goals	Subtypes	Prescription indication
Balance exercises	Exercises designed to improve posture, balance, and proprioception/ coordination	Maintain a sitting, standing, or walking position. Prevent body sway from its base of support Improve dynamic joint stabilization by maintaining joints in proper alignment during activity Improve muscle strength and control Facilitate patient injury recovery and independence Prevent slips and falls		Patient has difficulty maintaining a sitting, standing, or walking position

tioning and to minimize fall risk. A progressive gait training program is started once the patient is medically cleared:

- *Non-weight bearing (NWB)* – using parallel bars, frame, or crutches, full weight is placed on the uninjured leg and the upper extremities with no weight on the injured leg.
- *Partial weight bearing (PWB)* – if the amount or percentage of weight is unspecified, using bars, frame, or crutches, 20–25% (10–15 kg) of body weight is placed on the affected limb.
- *Full weight bearing (FWB)* – weight bearing as tolerated (WBAT), using a walking aid for balance, full weight is placed on the affected limb. Weight shifting exercises as tolerated.
- *Advanced gait training* – examples: balance board training, ambulation on uneven surfaces including slopes and jumping.
- *Functional exercise* – examples: climbing stairs, walking backward, getting up from the floor with or without a walking aid.

Respiratory Therapy

Respiratory therapy is a multi-technique approach to restore and maintain pulmonary function and prevent chest complications. It is indicated for patients on bedrest, those with thoracic and abdominal injuries or known respiratory diseases, and when prescribed by the surgeon/anesthetist. Interventions include postural drainage, chest percussion and clapping, expiration and inspiration techniques using a spirometer or a bottle, cough facilitation, and breathing exercises.

Casting and Traction

Pre- and post-surgery casting and traction are common rehabilitation interventions. Given the different techniques for application and removal of casts, uses of traction, and prevention of complications, education and training of team members, local staff, and patients/caregivers is essential and should be standardized within a mission (See Chap. 13).

Education

Rehabilitation effectiveness is increased by educating the patient/caregiver and should be provided at the beginning and end of each therapy session, at patient/caregiver meetings, and at discharge. Educational instruction sheets and guided patient demonstration can aid patient recall and accurate replication of exercises. Besides optimizing outcomes, physical rehabilitation provides social and psychological support.

Prosthetics and Orthotics

Prosthetics in austere environments typically involves replacement of an amputated lower limb with a prosthetic limb and rehabilitating the individual. If restoration of function is not desired or feasible, a prosthesis can still provide the patient with a sense of wholeness and wellness. Surgical teams should consult with and refer patients to a local P&O service provider early in the rehabilitation process. The patient will be assessed and measured and a prosthesis prescribed. Following fabrication and fitting, the individual receives therapy until function is optimized with ongoing evaluation and needed adjustment/maintenance of the prosthesis. An amputee is a patient for life. In natural disasters, Emergency Medical Teams following WHO rehabilitation recommendations have P&O expertise, consumable supplies and equipment, and mobility devices to manage some aspects of P&O care.

The primary general rehabilitation goal for a lower extremity amputee is to improve mobility in order that the patient becomes independent. Basic interventions include targeted exercise therapy, gait training, and education aimed to return the person to work and re-establish his place in society. The general amputee rehabilitation process in austere environments is presented in this ICRC video: *https://www.youtube.com/watch?v=Nfdp1w1jedE* (See Chap. 43).

Orthotics care usually involves the use of splints following a peripheral nerve or muscle injury to achieve proper joint positioning and to facilitate specific movements that will improve function. Other common indications are burns, hand injuries, and tendon transfer surgery. Postsurgical splinting provides immobilization, stability, and protection. Orthoses also correct and prevent deformities and soft tissue contractures. Table 45.2 lists general types of splints and their use. Common splinting materials used in LMIC include plaster of Paris, fiberglass casting material, and thermoplast. Demand for orthoses in austere environments is usually underestimated, especially in disasters, due to incomplete and irregular patient assessment.

Table 45.2 Splint type, description, and function

Splint type		Function
Static splint	No moving parts; does not permit body movement	Provides stability, immobilization, and protection Provides joint/extremity positioning for function Prevents soft tissue contracture and further deformity Prevents muscle/tendon shortening
Serial static splint (static progressive splint)	Adjustable; permits change in joint position/ROM	Increases joint end range progressively Elongates soft tissue progressively Provides graded tissue stretching (ROM)
Dynamic splint	Moving parts permit motion	Provides compensatory movement Supports joint/extremity in proper alignment Maintains joint function Aids ROM exercising using varying resistance Promotes tendon gliding to decrease adhesions

Challenges of Physical Rehabilitation in Austere Environments

Individual and health system barriers to the delivery of orthopedic services in austere environments (see Chap. 5) apply to the delivery of rehabilitation services. Successful mitigation of barriers is necessary for individuals, caregivers, and families to recover physical function and to live fully. Every mission team in LMIC disaster and conflict settings is confronted with challenges presented by constantly changing operational requirements. Consideration of the planning, coordination, and rehabilitation practice guidance presented in this chapter will help reduce these barriers. Reliance on established patient triage, assessment, and injury-specific management protocols is necessary to effectively achieve desired rehabilitation treatment goals and patient outcomes. Best technical rehabilitation practice should be employed using local, low-cost materials, and low-technology interventions that can be performed by the patient/caregiver at home. Given limited resources, rehabilitation providers must innovate strategies and therapies. Provider resourcefulness and adaptability are emphasized in this ICRC video which profiles the roles of the prosthetist/orthotist and physiotherapist in an austere environment: https://www.youtube.com/watch?v=OOYCRGB0bn0&t=158s).

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Appendix 1: Head Trauma and Basic Management of Brain Injury and Elevated Intracranial Pressure

Ercan Tureci

Primary traumatic brain injury occurs at the time of the impact. Secondary brain injury occurs from (1) local intracranial insults such as elevated intracranial pressure, edema, hematoma, and seizure and (2) systemic insults such as hypoxia, hypercapnia, hypotension, and electrolyte/metabolic disorders. The severity of the initial injury, as defined by the Glasgow Coma Scale (GCS), is predictive of eventual outcome: GCS 14–15 mild, 9–13 moderate, and 3–8 severe head injury. The correlation between GCS and survival is nonlinear, with a high rate of mortality for GCS 3–7 and a decline in mortality between GCS 8 and 15.

Glasgow Coma Scale (GCS)

Score	Infant <1 year	Child 1–4 years	Age 4–adult
Eye opening			
4	Spontaneously	Spontaneously	Spontaneously
3	To voice	To voice	To voice
2	To pain	To pain	To pain
1	No response	No response	No response
Verbal response			
5	Coos, babbles	Orientated, speaks, interacts, social	Orientated
4	Irritable cry, consolable	Confused speech, disorientated, consolable	Confused, disorientated
3	Cries persistently to pain	Inappropriate words, inconsolable	Inappropriate words
2	Moans to pain	Incomprehensible, agitated	Incomprehensible sounds
1	No response	No response	No response
VR for intubated age 4–adult patients: 5 appears able to converse, 3 questionable ability to converse, and 1 unresponsive			
Motor response			
6	Normal spontaneous movement	Normal, spontaneous movement	Obeys commands
5	Withdraws to touch	Localizes pain	Localizes pain
4	Flexion withdrawal	Flexion withdrawal	Flexion withdrawal
3	Abnormal flexion	Abnormal flexion	Abnormal flexion
2	Extension	Extension	Extension
1	No response	No response	No response

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Management of Head-Injured Patients and Control of Intracranial Pressure

- Airway management
- Elevate head of bed 15–45°
- Oxygen; SpO_2 >95%, Hb 8.5–10 g
- Adequate analgesia
- Sedation, if necessary and after initial assessment
- Osmotic diuresis: Mannitol 0.25–1 g/kg every 4–6 h
- Lasix 0.5–1 mg/kg IV
- Avoid hypotension with adequate fluid resuscitation ± vasopressor
- Seizure prophylaxis: Phenytoin 15 mg/kg IV load, then 100 mg IV/PO/TID or 5–2 mg/kg. In children use with discretion
- Avoid hyperthermia and hyperglycemia
- Diabetes insipidus: Desmopressin 1–4 μg IV daily to maintain urine outputs of 100–150 mL/h
- Gastric ulcer prophylaxis: Omeprazole-Pantoprazole 40 mg IV – OD
- Thromboprophylaxis: Elastic stockings, *no* anticoagulants if suspect intracranial bleeding
- *No* role for parenteral corticosteroids

Appendix 2: WHO Surgical Safety Checklist

World Health Organization

SURGICAL SAFETY CHECKLIST (FIRST EDITION)

Before induction of anaesthesia ▶▶▶▶▶▶▶▶ Before skin incision ▶▶▶▶▶▶▶▶▶▶▶▶▶▶ Before patient leaves operating room

SIGN IN

☐ **PATIENT HAS CONFIRMED**
- IDENTITY
- SITE
- PROCEDURE
- CONSENT

☐ **SITE MARKED/NOT APPLICABLE**

☐ **ANAESTHESIA SAFETY CHECK COMPLETED**

☐ **PULSE OXIMETER ON PATIENT AND FUNCTIONING**

DOES PATIENT HAVE A:

KNOWN ALLERGY?
☐ NO
☐ YES

DIFFICULT AIRWAY/ASPIRATION RISK?
☐ NO
☐ YES, AND EQUIPMENT/ASSISTANCE AVAILABLE

RISK OF >500ML BLOOD LOSS (7ML/KG IN CHILDREN)?
☐ NO
☐ YES, AND ADEQUATE INTRAVENOUS ACCESS AND FLUIDS PLANNED

TIME OUT

☐ **CONFIRM ALL TEAM MEMBERS HAVE INTRODUCED THEMSELVES BY NAME AND ROLE**

☐ **SURGEON, ANAESTHESIA PROFESSIONAL AND NURSE VERBALLY CONFIRM**
- PATIENT
- SITE
- PROCEDURE

ANTICIPATED CRITICAL EVENTS

☐ **SURGEON REVIEWS:** WHAT ARE THE CRITICAL OR UNEXPECTED STEPS, OPERATIVE DURATION, ANTICIPATED BLOOD LOSS?

☐ **ANAESTHESIA TEAM REVIEWS:** ARE THERE ANY PATIENT-SPECIFIC CONCERNS?

☐ **NURSING TEAM REVIEWS:** HAS STERILITY (INCLUDING INDICATOR RESULTS) BEEN CONFIRMED? ARE THERE EQUIPMENT ISSUES OR ANY CONCERNS?

HAS ANTIBIOTIC PROPHYLAXIS BEEN GIVEN WITHIN THE LAST 60 MINUTES?
☐ YES
☐ NOT APPLICABLE

IS ESSENTIAL IMAGING DISPLAYED?
☐ YES
☐ NOT APPLICABLE

SIGN OUT

NURSE VERBALLY CONFIRMS WITH THE TEAM:

☐ **THE NAME OF THE PROCEDURE RECORDED**

☐ **THAT INSTRUMENT, SPONGE AND NEEDLE COUNTS ARE CORRECT** (OR NOT APPLICABLE)

☐ **HOW THE SPECIMEN IS LABELLED** (INCLUDING PATIENT NAME)

☐ **WHETHER THERE ARE ANY EQUIPMENT PROBLEMS TO BE ADDRESSED**

☐ **SURGEON, ANAESTHESIA PROFESSIONAL AND NURSE REVIEW THE KEY CONCERNS FOR RECOVERY AND MANAGEMENT OF THIS PATIENT**

THIS CHECKLIST IS NOT INTENDED TO BE COMPREHENSIVE. ADDITIONS AND MODIFICATIONS TO FIT LOCAL PRACTICE ARE ENCOURAGED.

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Appendix 3: Bone Graft

Richard A. Gosselin and Michelle Foltz

Bone graft may be necessary to aid fracture healing and fill bone cavities or defects [1]. It has three interconnected properties:

1. Osteoconduction: provides a structural scaffold for bone growth
2. Osteogenesis: provides living cells that directly stimulate bone growth
3. Osteoinduction: provides chemical factors that promote bone growth, such as the bone morphogenetic protein (BMP) group

It can consist of cancellous, cortical, corticocancellous, or vascularized bone. It can act purely as a space filler or provide some (sometimes all) structural stability. There are different types:

1. Autogenous: bone harvested from the patient itself, this is the safest form.
2. Allogenous: harvested from human cadaveric donor. This can be fresh-frozen, freeze-dried (lyophilized), or demineralized (croutons).
3. Synthetic: calcium sulfate, phosphate, carbonate, silicone, or aluminum based, which come as pellets, powders, or pastes. They may be enhanced by biologically active adjuvants such as BMPs, growth factors, etc., delivered by gel or paste.

Allografts carry an immunogenic potential: transmission of HIV and Hep A and B and others are all well documented. They are rarely available in LMICs and very expensive. This is also true of more sophisticated bone-harvesting tools such as the reamer-irrigator-aspirator (RIA) and will not be discussed.

Structural autografts can be obtained from the iliac crest, fibula, or ribs. They are cortical or corticocancellous and non-vascularized, thus requiring a long time to incorporate. Cancellous autograft is usually obtained from the anterior iliac crest, or more rarely from the posterior iliac crest, which requires a lateral or prone position to harvest. Depending on the quantity needed, small amounts of cancellous bone can be harvested through a cortical window from the distal radius, olecranon, distal femur laterally, or the proximal tibia medially. This avoids iliac crest morbidity, preserves iliac crests for future use, and benefits from a tourniquet already in place [2].

If there is any doubt that the proposed recipient site is infected, it is best to first surgically confirm its suitability and only then harvest the bone graft, ideally using a separate set of instruments from a separate table.

Harvesting the Anterior Iliac Crest

Unless contraindicated, put a bump/pillow/saline bag under the buttock to elevate the pelvis a few degrees. Even if potentially less comfortable for the patient, we use the crest on the same side as the index procedure, so the patient still has a non-operated side to stand on. The skin incision should not be directly over the crest but a finger breadth

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above or below it, to prevent painful rubbing of a scar against the prominent crest from pants/belts. The avascular aponeuroses of the abdominal and gluteal muscle groups are divided along their junction, going no further anteriorly than 1–2 cm from the anterior superior iliac spine to avoid injury to the lateral femoral cutaneous nerve. The inner, outer, or both tables are exposed subperiosteally. Inserting and packing a sponge with an elevator to separate the periosteum from the bone is relatively atraumatic way to expose the flat table of ilium. We prefer using the inner table: visualization is better, and when sitting or standing, gravity pushes the soft tissues against the donor site to help with hemostasis. When using the outer table, gravity pulls the tissues away from the donor site, creating more post-op pain and bleeding.

We like to use a large curved osteotome or Taylor retractor, inserted deeply and hammered through both tables of the ilium to serve as a retractor. Smaller, sharp, straight, and curved osteotomes are used to lift 1–2 cm struts of corticocancellous bone, as thin as possible, starting at the crest and working the cortical cuts down to the retractor. Curettes and gouges of different sizes are used to harvest as much cancellous bone as needed and available from between the two iliac tables. The cancellous bone on the undersurface of the crest is often quite generous and should not be overlooked. The crest thins from front to back and extending the exposure posteriorly may not significantly increase the amount of cancellous bone attainable. When in doubt as to the quantity needed, the other crest should be prepared, just in case. Bone grafts to fill large defects may need all four crests.

The harvested bone is secured in a dry cup (do not put in saline or worse, betadine) and covered with a wet sponge to prevent drying until used. All scrubbed staff should be acutely aware at all times of its location to minimize all threats to its loss. There is no worse feeling than hearing the metallic cling on the floor from the dropped cup full of recently harvested graft. We do not use bone wax or gelfoam and only rarely a drain. We try to tack down the previously elevated periosteum with a couple of trans-osseous sutures; the wound is closed in layers; and, where available, we infiltrate the wound with generous amounts of ropivacaine, bupivacaine, or other long-lasting local anesthetic [3]. Complications such as hematoma, meralgia paresthetica, or paralytic ileus are rare, but pain from the donor site is often severe.

In austere settings any non-union or delayed union needing surgery will likely need bone grafting to ensure healing. When in doubt, it is better to err on the side of early bone graft rather than waiting or having to return to the OR for a second procedure. Be aware that in cultures with a high rate of osteoporosis in females, the amount of available bone graft can be severely limited, and its lack will affect outcomes.

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Appendix 4: A Low-Cost Method of Negative Pressure Wound Therapy (NPWT)

Jair Kimri Jingco and Nadine Semer

The number and variety of improvised NPWT systems found in austere settings use a wide variety of off-the-shelf, locally available materials. Vacuum sources range from modified fish tank pumps (Fig. A4.1d) [1, 2], wall suction, portable suction machines, or a suction drain attached to a Hemovac or other vacuum-producing reservoir. Gauzes of various absorbencies, foam stuffing from local furniture makers, and kitchen sponges substitute for pricey open-cell foam. The impervious plastic material securing the vacuum over the wound ranges from expensive adhesive surgical sheets to plastic bags from the bazaar, unspooled food wrap, or press seal secured to the skin with or without a coat of benzoin, mastisol, skin bonding latex adhesive, or skin tac liquid adhesive,[1] fortified with duct or other tape at the skin-plastic interface. Sterility of the absorbent material can arrive prepacked from the manufacturer, sterilized by steam or gas, or microwaved.

NPWT systems have improved wound care by decreasing surrounding tissue edema while keeping the wound moist to promote healing (Fig. A4.1a–c). They can be applied after the initial wound debridement, in preparation for skin graft, after application of skin graft, over a closed surgical wound, or at any stage in the healing process [3].

[1]Latex and other skin adhesives are used for securing medical devices to skin. The residual adhesive at dressing change can be removed with nail polish remover or a product-specific solvent.

Do-It-Yourself Negative Pressure Wound Therapy

Supplies

- Flexible tubing—16–18 Fr NG or suction tubing, possibly adding additional side holes
- Impermeable dressing—self-adhesive Opsite or multiple layers of food wrap
- Absorbent dressing material—gauze, prep sponges, OR towels, Kerlix, or kitchen sponges
- Suction apparatus

Instructions

Place absorbent dressing material onto and completely covering and filling the bed of the clean wound to the edges.

Place tubing within gauze layers, into a cut or trough in the foam, or on top of this material, not directly on the wound.

Cover with adhesive dressing or layers of food wrap secured to skin with skin adhesive and tape.

Connect to suction—75–100 mmHg—adults; 60 mmHg—peds.

Change every few days as needed.

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Fig. A4.1 (**a**) Foot of a child 5 days after debridement following gunshot wound with open fractures of fourth and fifth MTs and cuboid. (**b**) Wound after further debridement of exposed bone and first 3-day fish tank NPWT that has produced fine granulation lining deep bony cavity. (**c**) SSG after second NPWT application. (**d**) Application of fish tank pump and food wrap over gauze to make a negative pressure assemblage

With NPWT application over hand and foot wounds, be careful that interdigital areas are protected from prolonged skin-to-skin contact as moisture can readily macerate the skin. Splint wrists, fingers, and ankles with plaster of Paris slabs for comfort, to prevent unwanted motion and to preserve functional position. Keep in mind that tight, circumferential dressings are constrictive. Careful monitoring of distal circulation is mandatory.

For wounds that will need both NPWT and an ex-fix, try to place the ex-fix away from the wound. Modeling clay or materials used to secure colostomy dressing can be placed around the pins at the plastic wrap interface to help seal the vacuum and prevent leakage from the irregular and difficult to secure edge.

After application, elevate appendages on pillow or place bed blocks and check for distal edema.

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Appendix 5: PVC Humeral Fracture Brace

Jair Kimri Jingco

An inexpensive, effective humeral fracture brace can be made from 4″ PVC tubing, cut into 1/3 tubular sections. The shorter, medial piece has slits to secure two rows of 2–1.5 in. Velcro strapping (Fig. A5.1a). An inner sleeve of thin plastic, such as the cover from a binder (upper right of Fig. A5.1a), has corresponding slits to match those on the medial PVC segment. Velcro strapping is threaded through the slits in the PVC and inner sleeve. The construct is secured over stockinette or a sock on the upper arm. An additional proximal strap around the chest can improve stability early in the treatment (Fig. A5.1b, c). X-ray with the brace showing the two PVC components, the inner sleeve, and a well-aligned closed comminuted mid-shaft humerus fracture. Complete instructions and patterns available at https://orthopodsworkbench.blogspot.com/.

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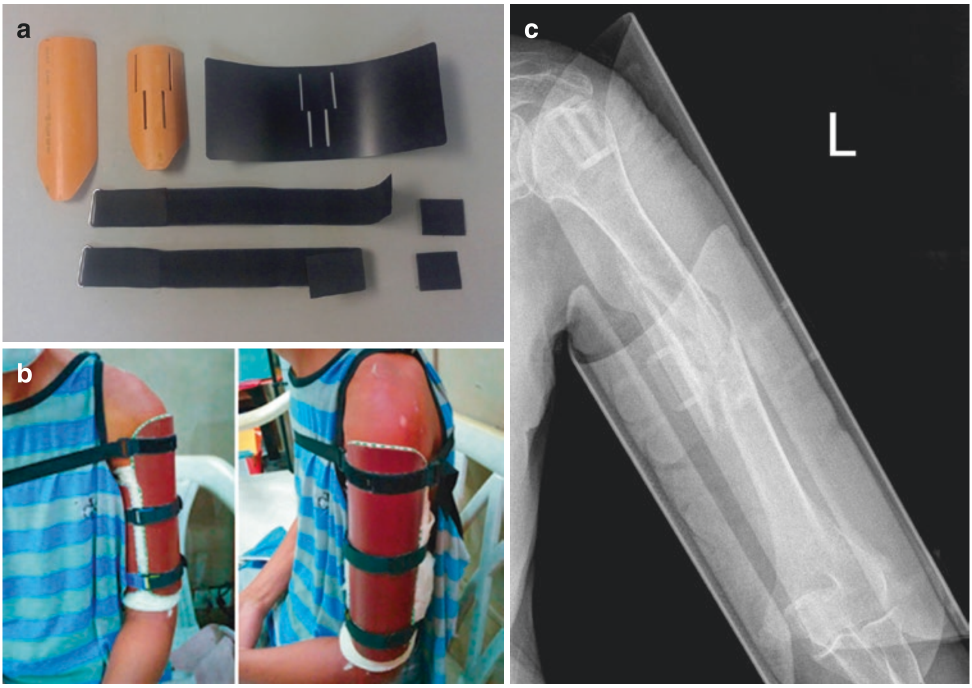

Fig. A5.1 (**a**) Components for making humeral fracture brace. Top from left to right: lateral PVC component, medial PVC component with slots to thread Velcro straps, plastic inner liner with slots corresponding to those in medial PVC component. Bottom: Velcro. (**b**) Fitted PVC humeral brace with superior chest strap for early stability. (**c**) X-ray of fractured humerus in PVC brace

Appendix 6: Tips, Tricks, and Pearls

Lower Extremity

Tibial nailing. Without a fracture table, tibial nailing can be done by "breaking" the OR table and hanging the leg over the end. With tables that do not "break," a triangle is useful. Ex-fix rods clamped together and cushioned with drapes can be fashioned into a reasonable triangular support placed under the knee to maintain flexion while nailing.

Holding a closed reduction during tibial nailing is facilitated by wrapping an Esmarch or elastic bandage around the leg. Long broad DCPs or ex-fix bars wrapped against the leg give extra support while maintaining the alignment. NB: check availability of Esmarch or other bandage the day before as many ORs do not keep them sterile.

Distal locking standard IM nails without fluoroscopy. A nail of equal length as that used in the patient is secured proximally close to the patient's skin using two Steinmann pins, K-wires, or long drill bits placed through the "external" nail and the cannulae in the proximal targeting jig. The distal femur/tibia is widely exposed with one incision in the vicinity of the distal interlocking holes of the "external nail." The lateral cortex is drilled under direct vision and the hole made larger with bigger drill bits, T-handle reamers, curettes, or small rongeurs to expose the nail and hopefully the hole, if the nail has not deformed too much.

Good lighting and a small suction tip, preferably metal, with irrigation will help the process. The nail may need to be rotated to expose the hole, unless an IM interference fit prevents this. Even with minimal lateral screw purchase, there should be enough purchase with engagement of the medial cortex to control rotation and shortening, even if the overall construct is obviously weak.

An alternative is to open a 2 × 3–4 cm window exposing the distal nail, drill the medial cortex under direct vision of the holes, and secure the window back in place with two screws that abut the nail, giving some increased contact. These techniques should be strong enough to allow early mobilization and active ROM, but weight-bearing should be delayed.

Shaping templates for cutting known osteotomy angles. Using a sterile glove envelope, measure and mark on one side 1 unit from the corner. On the adjacent side, mark three units. Units can be the width of an osteotome (Fig. A6.1), width of a maximally opened hemostatic or Kocher clamp, or anything that is handy. A line from the first of the three marks to the one mark has corner angles of 45°. A line from the second of the three marks to the one mark has a corner angle of 22°, and a line from the third mark to the one mark is 11°, and so forth (Fig. A6.2). Wedges of desired angles can be cut from the glove envelope with reasonable accuracy.

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Fig. A6.1

Fig. A6.2

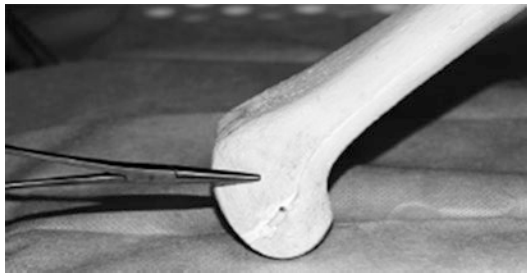

Fig. A6.3

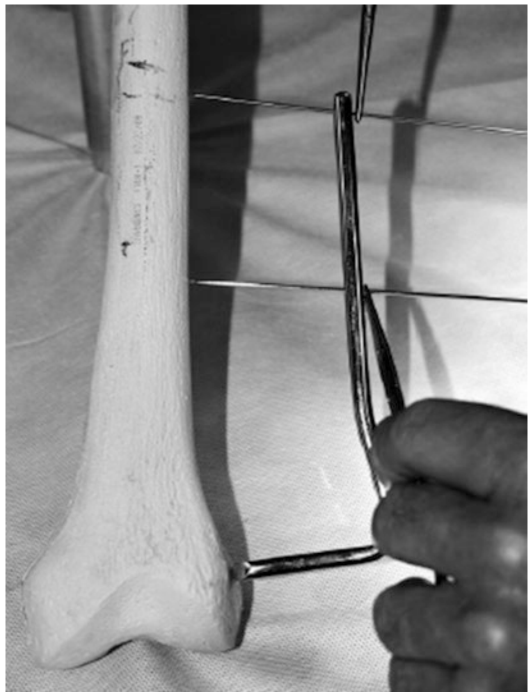

Fig. A6.4

Angles can also be estimated by opening a Kocher clamp so the jaws are at right angles and measuring the distance between the tips. Closing the distance by half yields an angle between the jaws of 45°. Halving the distance again gives an angle of about 22° and, again, about 11°.

How to use a blade plate. The blade entry site in the femur is selected below the epicondyle and marked. It should be 1.5–2 cm above the joint line and centered at the junction of the anterior 1/3 and posterior 2/3 (Fig. A6.3). The plate part is positioned parallel to the shaft where it will lie. This is made easier by drilling K-wires through two proximal holes, clamped at the outer side of the plate so that they are equidistant from the cortex (Fig. A6.4).

A third K-wire is inserted in line with the blade in the distal fragment (Fig. A6.5). A plate (or an ex-fix bar or two bars acting as a sandwich) can be used to verify that the three K-wires are in the same sagittal plane. A fourth K-wire is drilled at the desired angle of correction at the blade entry site, using the cut wedges as a guide (Fig. A6.6). The third pin is removed.

The contours of the blade entry site are marked with pen or electrocautery (Fig. A6.7). The entry site is predrilled with a small bit (Fig. A6.8), and a narrow chisel or osteotome is used to tunnel the metaphysis, staying in line with the fourth K-wire and parallel to the blade plate in all planes. Without fluoroscopy, the appropriate depth needs to be guestimated, but a normal adult should be around 70–80 mm. Better too short than too long. The blade can be inserted at least halfway in open wedge or completely in closed wedge before doing the osteotomy.

The osteotomy site is marked, at least 1 cm proximal to the most distal screw in the blade plate, usually at the level of the offset (Fig. A6.9). For an open wedge, a transverse osteotomy is done with a

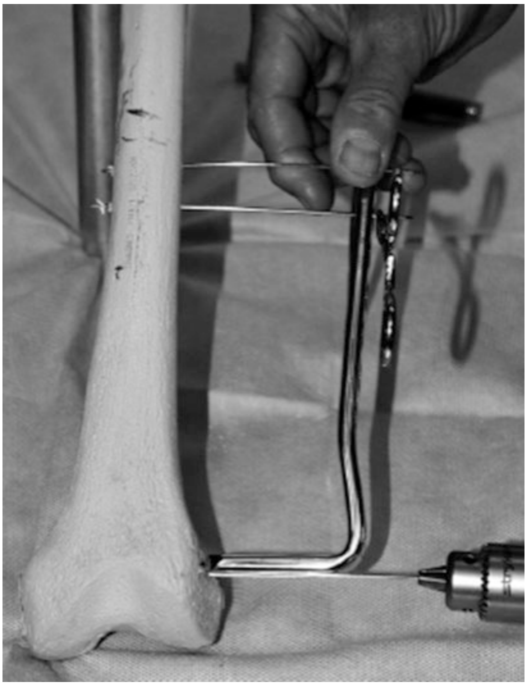

Fig. A6.5

Fig. A6.6

saw if available or with osteotomes connecting small drill holes using osteoclasis to keep a cortico-periosteal hinge on the opposite side. The blade is inserted and seated and the plate secured on the proximal fragment with a bone clamp.

A closed wedge requires the distal cut to be at the same location, with the proposed correction angle, and this is made easier by inserting the blade plate (Fig. A6.10). The initial cut is done as above, and the second osteotomy is done proximally, perpendicular to the long axis of the bone,

Fig. A6.7

Fig. A6.8

and triangulated to leave a cortico-periosteal hinge on the opposite side (Fig. A6.11). The blade plate is inserted and fixed in compression proximally (Fig. A6.12). If an opposite hinge has been preserved and the blade plate offset is adequate, translation should not be an issue (not the case in this example using a saw bone). Up to 1 cm is usually well tolerated, but more than that needs to be addressed with a different plate off-

Fig. A6.9

Fig. A6.11

Fig. A6.10

set. If contouring the plate is necessary, one needs to be acutely aware of not changing angles.

If ex-fix bars are not available. Large catheters or a medium-sized chest drain can be pre-filled with cement (bone cement if available, but more commonly dental) and inserted over the pins while still doughy.

Tips when casting without an assistant. For mid-shaft tibia or ankle fractures, place the patient supine with the leg hanging over the side and the thigh supported by a board. Loop a long swath of Kerlix or stockinette around the ankle and heel ending in a loop into which you can insert your foot to apply traction while rolling the cast. Stop the cast above the malleoli; remove the Kerlix traction when the POP has semi-set, making sure the undercast cotton padding is still intact without creases or bunching around the bony prominences; and finish the cast with the ankle and foot in their proper positions.

For a below cast when the fracture (tibia or ankle) is sticky and you are alone and need to keep the ankle at 90°. This technique requires a piece of wood about 1 cm thick, 6 cm wide, and 40–50 cm long. Have the patient sit with his legs over the side of the table, adjust the stool so that you are sitting on one end of the piece of wood and the other end is under the stockinette or cast padding, and support the sole of the foot with the

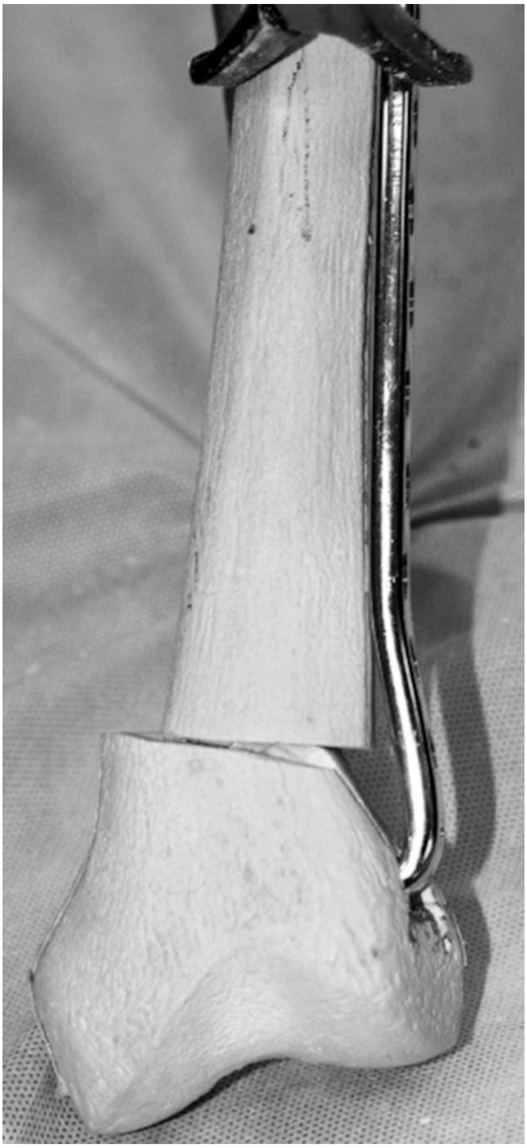

Fig. A6.12

ankle in neutral position. When the cast is finished, pull out the piece of wood.

In the same situation of fracture stickiness and working alone, a below knee POP applied with the patient prone and the knee flexed 90° helps maintain neutral ankle position.

Miscellaneous

A wooden arm board can be used for spica table. If narrow and thin enough, a wooden arm board can be incorporated in the spica and the patient slid off after completion. More commonly, the board (or even the regular armrest) is too wide but can support the head and proximal trunk while assistants hold the lower part of the child. This allows the head to stay close to anesthesia.

Ex-fix for phalangeal fractures. K-wires drilled through the plastic cap of a syringe needle, through the bone, above and below the fracture, make an ex-fix for open phalangeal fractures. Use one or two K-wires on each side of the fracture, depending on stability. Figure A6.13a shows a near amputation of a thumb through the proximal phalanx from a sugarcane grinder, with four K-wires through a needle cap. Figure A6.13b shows postreduction X-ray, with restoration of length.

Neatly splitting a tendon for Z-plasty. Using an 0 or 00 monofilament suture on a needle, penetrate the tendon in the middle and cut proximally and distally as needed, as if using a Gigli saw. Divide the tendon at the appropriate ends.

When putting on pelvic ex-fix. Use an incision long enough to put the thumb and finger on the inner and outer tables to sense pin placement. If a pin breaches the cortex, it needs to be the inner table, as these ex-fix are usually loaded in compression. Alternatively, specially in a damage control situation, pins can be inserted blindly in the supra-acetabular area, approximately two finger breath above and anterior to the tip of the greater trochanter and at a 45° angle.

Portable instructions. With a sharpie or pen, mark on the cast, dressing, or even adjacent skin when it was done, when it needs to come off, or the date of the next planned procedure (Fig. A6.14).

Skin hooks. These can be made from two syringe needles bent at the tips and held with hemostats.

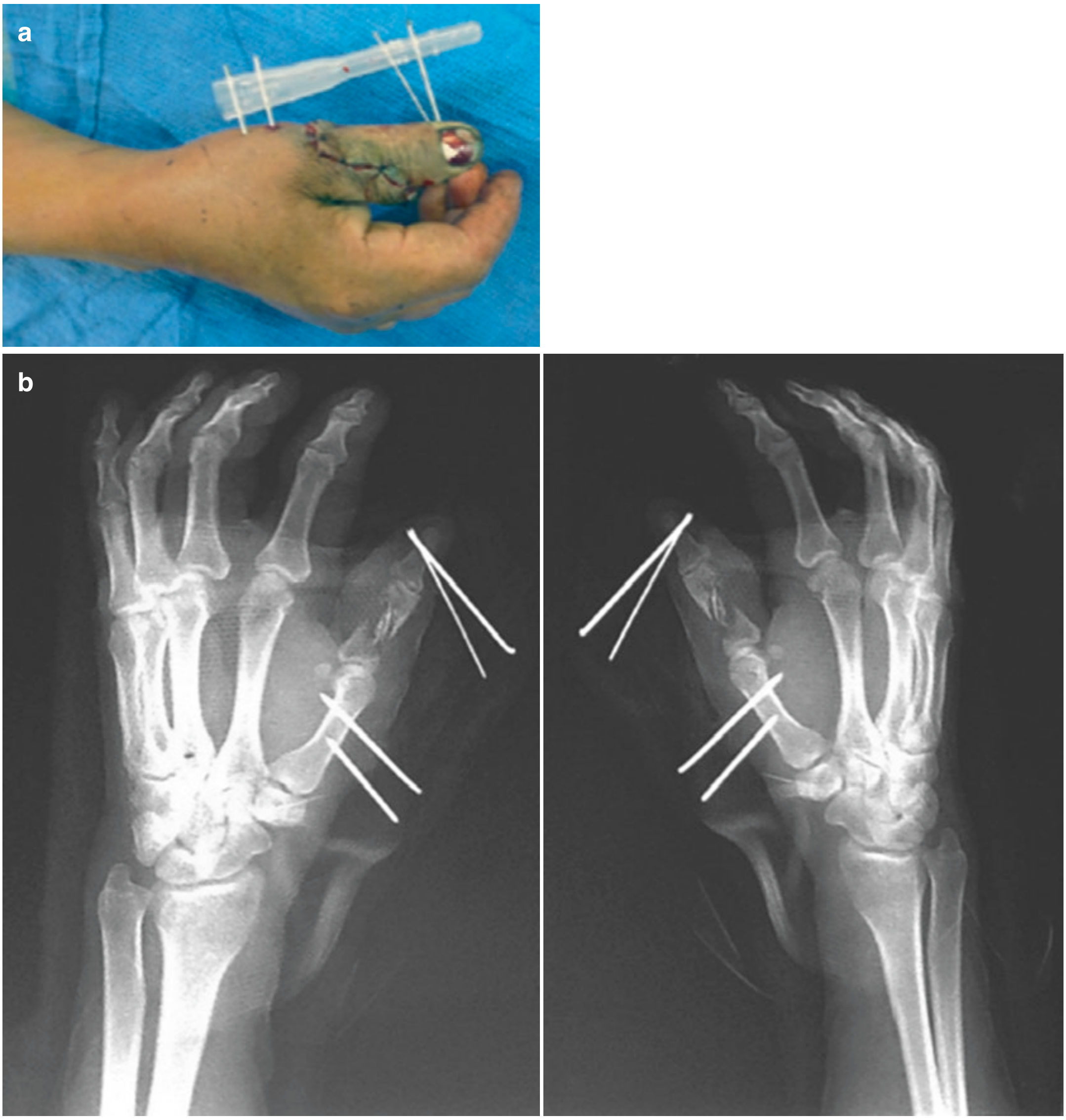

Fig. A6.13

Fig. A6.14

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