Orthopaedic Curriculum
Pan-African Academy of Christian Surgeons

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This is the collaborative work of the Orthopaedic Task Force of the Pan-African Academy of Christian Surgeons (PAACS). Each chapter was authored by orthopaedic and plastic surgeons who have participated in surgical mission work in the developing world. The intent of this publication is to provide an educational resource for the surgical residents in the PAACS program and ultimately for the glory of God.

This curriculum is intended solely for the education of the surgical residents within the PAACS program and is not intended for commercial gain.

Douglas W. Lundy, MD, FACS – Atlanta, Georgia, USA – January 2011.

Open Fractures

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INTRODUCTION

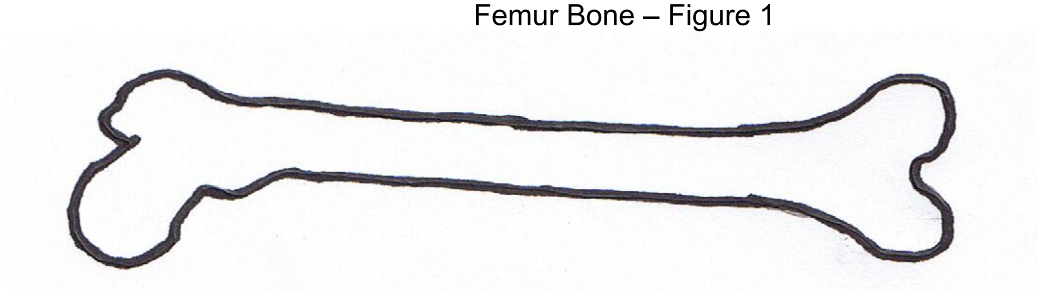
Open fractures occur when a bone(s) penetrate the skin following trauma. The diagnosis can be difficult (as with a small skin puncture) but it is most important not to miss. Most often the findings are obvious.

The overall goal for open fracture care is to attain a well-healed, non-infected wound and to restore function. Quality and quantity of bone healing is directly related to the vascularity re-established in the wound as well as close approximation of the injured tissues. Treatment is aimed at providing the optimal conditions to allow the human body biochemical pathways to produce the innate processes of healing to occur.

Bone consists of two forms of tissues. The outer or hard tissue is the **cortex** or cortical bone and the inner, softer, spongy bone is called the **cancellous** or medullary bone. The broken cortical bone usually produces the open fracture when it punctures or lacerates the skin.

Anatomically the long bone is divided into three anatomical areas: the **epiphysis**, the **metaphysis** and the **Diaphysis** demonstrated in **Figure 1**. In children, the epiphysis is the area where most growth occurs and in children and adults is located on either end of the bone. The metaphysis is located just below the epiphysis and is the tapered shape of the bone that leads to the diaphysis or shaft of the bone. The epiphysis and metaphysis will be on each end of a long bone with the diaphysis in the middle.

Femur Bone – Figure 1



Epiphysis Metaphysis Diaphysis Metaphysis Epiphysis

Any or all of these areas can be involved in an open fracture. If injury occurs in the epiphyseal or metaphyseal area, think of joint involvement. With diaphyseal fractures don't overlook injury to the joint above or below the break (i.e. a femur shaft fracture associated with an ipsilateral hip dislocation or fracture). One should also be aware of the anatomical location of major vessels or nerves in association with these fractures. Sharp bones not only penetrate skin but can also lacerate these structures.

Another important structure of bone is the lining on the outside of the bone called the **periosteum**. Much of the blood supply to the bone will reside in this tissue. It is important in any fracture to try and preserve this periosteum and protect it during surgery. Stripping of periosteum unnecessarily will affect the bone healing.

Bone fracture healing (as with other tissue healing) occurs in three phases: inflammation, repair, and remodeling illustrated in **Figure 2**.

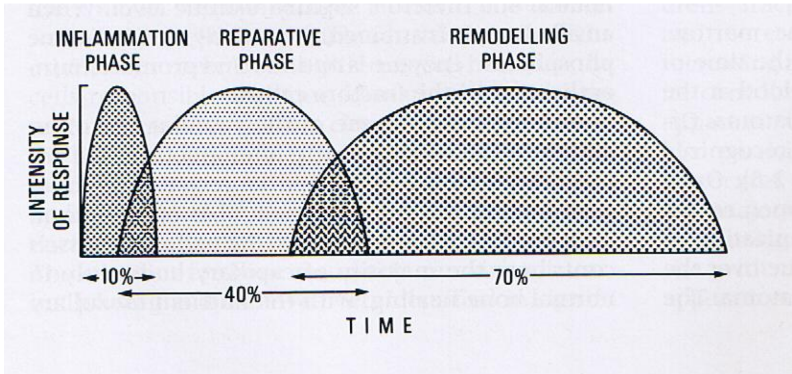
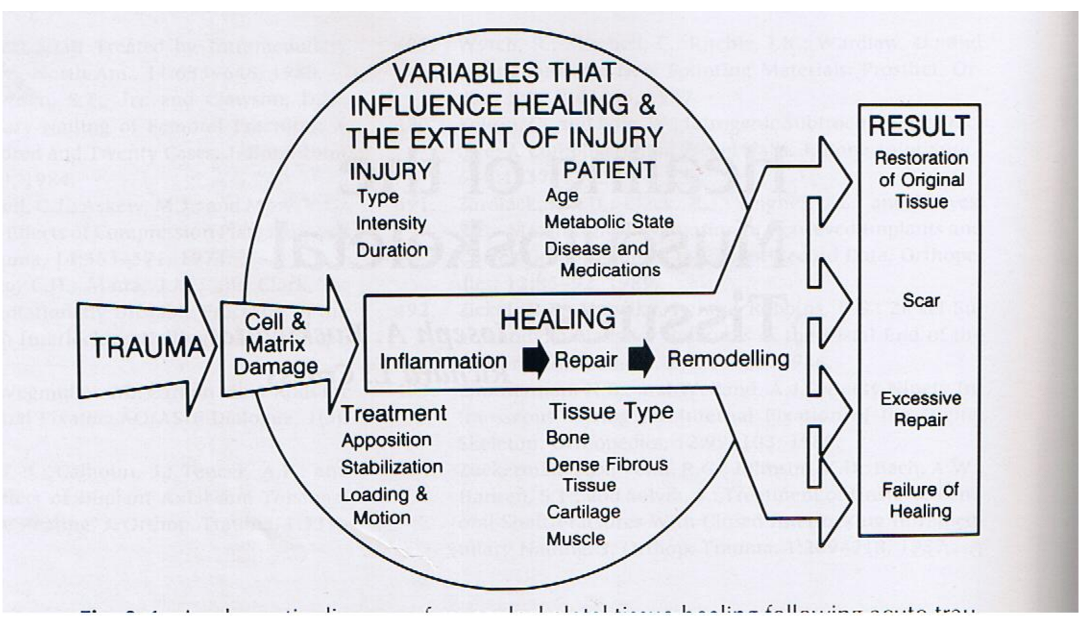


Figure 2

The inflammatory phase may last days to weeks. The reparative phase will last more than a month and usually several months. The remodeling phase for bone can take a year or more. The actual amount of time for a specific bone to heal is dependent on many factors. Among others are the location of the fracture (i.e. a distal tibia fracture will take longer than a proximal 3rd tibial fracture due to the vascular rich muscular envelope in the proximal part of the bone), the amount of comminution of the fracture, whether the fracture is open or closed and the severity of the injury. The latter is probably the most critical determining factor leading to the final result.

Figure 3 shows some the variables that influence healing in bone and other tissues and the results obtained.



FRACTURE CLASSIFICATION

Long bone fracture classification can be made by the **configuration** of the fractured bone as noted in **Figure 4**. Classifications not only are helpful in communicating types of fractures to others but knowing the type of fractures is beneficial in treatment planning.

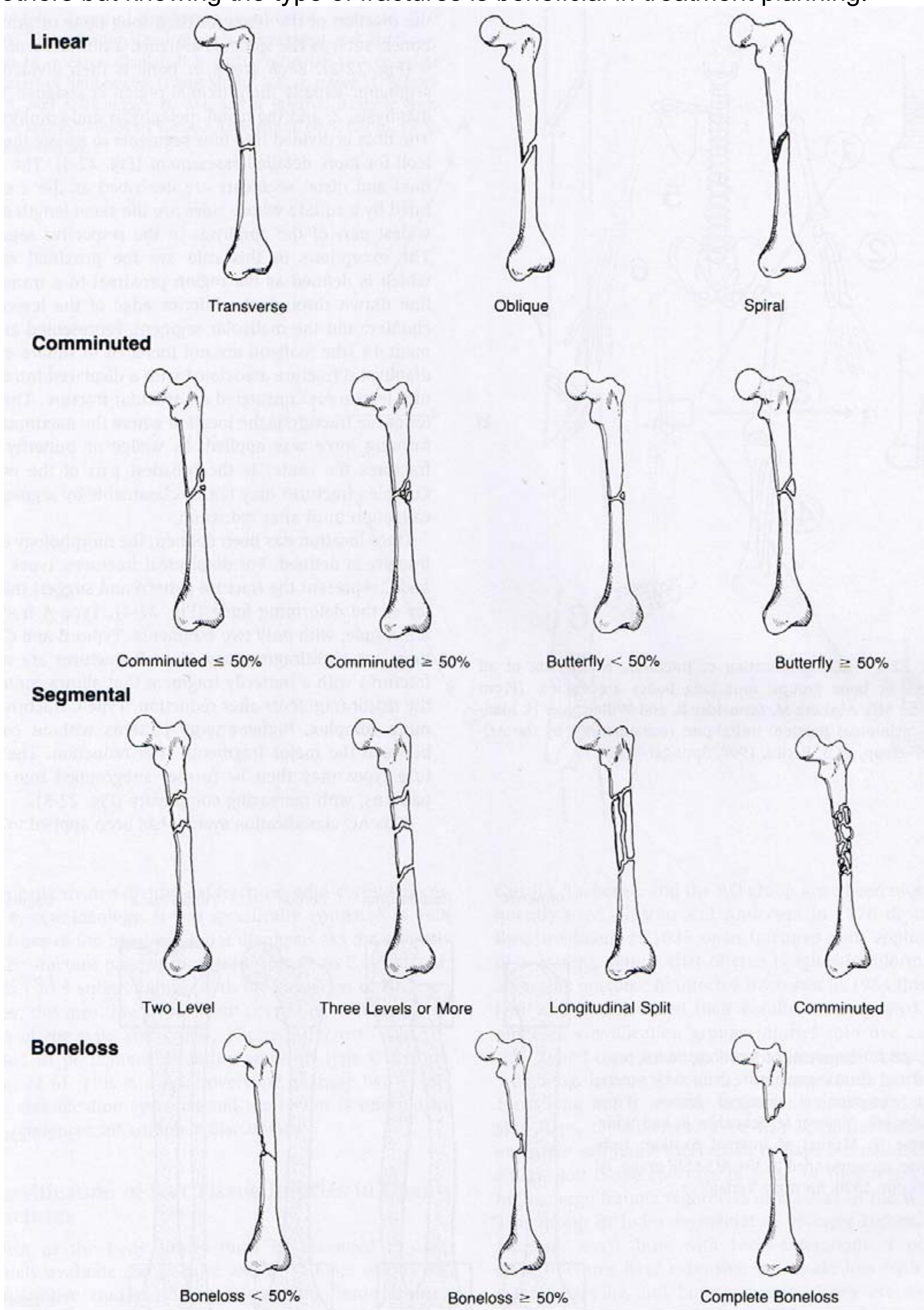


Figure 4

Of particular importance is **the classification of open fractures**. In this incidence the proper classification can mean the survival of the extremity. The most popular classification for open fractures is listed in **Figure 5**.

Type	Wound	Level of Contamination	Soft Tissue Injury	Bone Injury
I	<1 cm long	Clean	Minimal	Simple, minimal comminution
II	>1 cm long	Moderate	Moderate, some muscle damage	Moderate comminution
III*				
A	Usu. >10 cm long	High	Severe with crushing	Usu. comminuted, soft tissue coverage possible
B	Usu. >10 cm long	High	Very severe loss of coverage	Bone coverage poor; usu. requires soft tissue reconstr. surg.
C	Usu. >10 cm long	High	Severe loss of coverage plus vas. injury requiring repair	Bone coverage poor; usu. requires soft tissue reconstr. surg.

*Segmental fractures, farmyard injuries, fractures occurring in a highly contaminated environment, shotgun wounds, or high-velocity gunshot wounds automatically result in classification as a Type III open fracture.

Figure 5

TREATMENT

Initial evaluation consists of a history of the patient as well as the injury (if available) and a thorough physical examination (keeping in mind that an open fracture most often requires a trip to the OR and anesthesia). The exam of the open fracture focuses on the wound and includes evaluation of the neurovascular status of the extremity. Try to determine the neurovascular status before straightening the extremity to be sure no further damage is done with initial reduction and splinting. After placing the extremity in a more anatomical position (if angulated or rotated), re-check the neurovascular status to determine any change. **Initial treatment** of open fractures begins immediately in the emergency area with superficial cleansing of the wound with sterile saline and removal of obvious foreign bodies. A sterile dressing is placed to prevent further contamination. A temporary splint can be applied to allow moving the patient without further damage to tissues. IV antibiotics are given as soon as possible. Usually a cephlasporin is given with Type I and II fractures. An aminoglycoside is added with more contaminated wounds and penicillin included if farm injuries (i.e. fecal contamination with possibility of clostridium inoculation). An open wound is contaminated but not considered infected unless over 12 hrs old. Status of tetanus immunity should be determined and the appropriate protocol given.

Good-quality AP and Lateral **x-rays** of the fracture, including full visualization of the joints above and below, is the minimum examination necessary in any open fracture. In particular look not only at the fracture but also look for evidence of foreign material in the tissues not seen with initial physical examination. Notice any air that might be present in the soft tissues (especially away from the fracture site) and in particular if the fracture is near a joint, look to see if there is any air in the joint space indicating penetration.

Definitive care of the open fracture takes place in the OR. After transfer to the surgical table, if an extremity is involved, apply a tourniquet as high as possible to be inflated later as needed. Remove the dressing and cleanse the wound again with sterile saline. The extremity is then prepped as in a normal surgical procedure. However extreme care should be taken by the prepping team to support the fracture at all times to prevent further damage to the tissues. The wound is then draped with sterile surgical drapes. The surgical table should have a sterile waterproof covering especially if the surgical drape is cloth.

Formal debridement of the wound is begun. Intermittent irrigation is performed throughout the procedure as devitalized tissues are removed. It has been shown that there is a decreased infection rate when more than 10 liters of irrigation is used during the procedure. Therefore, irrigation is almost equally as important as removal of all nonviable and contaminated tissue. Optimum irrigation is performed with a shower type spray pulsatile irrigation unit (if available) however; most OR's will have a bulb syringe (less effective) or the sterile irrigation solution can be poured directly into the wound. Water pik type irrigation should not be used in that the contaminant can be driven further into the wound.

Where adequate **skin** is available, sharp excision of 1-2-mm of the contaminated and contused skin is made. The wound can then be enlarged to give adequate exposure to all tissues necessary to debride and explore vital structures as indicated (i.e. vessels and nerves). The wound should only be enlarged to normal appearing tissues. Keep in mind future closure of the wound when enlarging. Review established plastic surgery procedures if enlarging using flaps, z-plasty or if the original wound presents with unusual configurations.

A methodical layer-by-layer debridement is then made. After the skin, which should be conservative as possible, the devitalized **subcutaneous tissue** is removed. Most all dissection is made with a sharp scalpel. Any nonviable, damaged, or contaminated **fascia** is removed.

Determining the viability of **muscle** can be challenging. The characteristics of color, consistency, contractility, and capacity to bleed are the standards for determining muscle viability. It has been stated that if 10% of the muscle belly with its attached tendon is preserved, significant function is retained. If extensive damage is observed, questionable viable muscle could be preserved and re-debrided within 24-48 hrs. However necrotic muscle is a major source for bacterial growth and every effort should be made to remove all nonviable muscle tissue. At this point consideration should be made to releasing the fascia (i.e**. fasciotomy**) overlying the muscular compartments to accommodate future swelling.

Tendons are usually not a major source for infection and unless severely damaged and contaminated, should be preserved. Preserve the peritenon (vascular covering of the tendon) where possible but if it is lost and the tendon is exposed then the tendon should be left with a moist dressing until it can be covered.

Small fragments of **bone** devoid of soft tissue attachment are removed. Small pieces of bone with intact periosteum and soft tissue should be retained to act as small grafts and stimulate fracture healing. Small fragments that are grossly contaminated with foreign material should be removed. Removal of large avascular fragments is more of a challenging decision. If there is any soft tissue attachment and the fragment can be cleansed well, it might be wise to retain it. Removal of a large fragment may necessitate the event of a delayed or nonunion but this is less challenging to treat than an infected nonunion.

The **periosteum** (vascular covering) of the bone should be preserved where able and unnecessary stripping of this structure should be avoided. Be careful when debriding other tissues or manipulating the bone that the periosteum is not damaged.

If a **joint** has been penetrated, the joint should be opened and explored. Most often after thorough cleansing, the synovial lining can be closed over a drain (preferably a hemovac type suction drain). However, if there is any doubt as to closure then leave open until the next debridement. Maintain moist sterile dressings over any exposed cartilage.

Fractures about or extending into the joint can be stabilized with smooth K-wires (as can fractures of the hand or foot). Extensive metal should not be placed in the wound with initial debridement. If in doubt about the cleanliness leave all metal out until a later date.

Nerves and vessels can be explored as encountered. Small vessels can be coagulated or ligated. Circulation through damaged large major vessels should be restored. Loss of total blood supply to the limb for more than 8 hours most often leads to amputation. A tourniquet can be used during surgery but should be used only when necessary to control bleeding and not more than a continuous 1½ hours.

If a nerve is transected, the surrounding tissues can be cleansed and repair performed at a later date.

In severe crushing injuries of extremities, the question of **amputation versus limb salvage** must be decided. Type III-C fractures where vascular repair is required, the injury is accompanied by complete transection of the posterior tibial nerve and the limb is nonviable is an indication for primary amputation. Other considerations to amputate for severe injuries include elderly patients with severe diabetes and vascular disease, the presence of other debilitating disease, chronic steroid use, and a compromised immune system particularly a history of AIDS.

Stabilization of the fracture is possible by several techniques. The most common for open fractures are casting, pins and plaster, external fixation or skeletal traction with balanced suspension. One should be well informed of each of these techniques and utilize the one that best fits the situation. Once reduction and stabilization is attained x-rays, if available should be made and adjustment to the reduction performed at that time or on return to the OR in a few days. The goals are stabilization of the fracture, mobilization of the patient as well as being able to inspect the wound. External fixation with through and through pins or half pins attached to a bar frame is a popular choice for open tibia fractures because it meets these goals. Pins above and below the fracture incorporated in a cast (pin and plaster) is another technique when the external frames are not available. However, a removable window must be made over the wound to allow for inspection. The cast itself should be well padded to allow for swelling and placed so that it can be bivalved if necessary. Traction with balanced suspension techniques are preferable for initial care of open femur fractures that require wound care. It may also be maintained for initial healing of the fracture after which a cast brace may be applied. With a Type I fracture, traction can maintain alignment and length and when the wound heals, internal fixation with an intramedullary rod, if available, can be performed with little increased risk of infection. Casting, usually with plaster or fiberglass co-apt splinting is useful for upper extremity trauma. X-rays (if available in the OR) are made after stabilization and if needed re-adjustment performed at this time or on return to OR.

Open wounds are usually not closed. At this point, if available, a culture of the wound may be made. Sterile dressings are applied and if there is exposed bone, tendons or joints then moist sterile dressings are placed. The patient is then transferred for post op recovery.

Diligent **post op care** is vital. Daily inspection and dressing changes using sterile technique is performed. IV antibiotics are continued for 3-5 days or as indicated by clinical evaluation of the wound. Longer use of antibiotics can lead to a super infection with opportunistic organisms. If the injury were highly contaminated or traumatic a return to the OR for re-debridement in 24-72 hours would be appropriate. Otherwise return to the OR in 3-5 days is usual. Type I fractures may not require a return to the OR unless for closure of the wound over a drain which should remain for 2-3 days after closure. Once the drain is pulled and the Type I fracture wound is healing well, it can then be treated as a closed fracture. Other wounds require good judgment as when to close. If primary closure is possible, use a drain for 2-3 days after closure. Antibiotics are continued a day or so after the drain is pulled. Again, if available, cultures can be made on the second return to the OR prior to closure.

If the wound cannot be closed primarily or there is exposed bone or tendon a plan should be in place to obtain coverage as soon as possible; usually at the second debridement (unless an unusually contaminated or traumatic wound requiring multiple debridements). Techniques of STSG, relaxing incisions, appropriately placed flaps, Z-plasty closures or muscle flaps may be necessary to obtain adequate coverage and closure. If a wound is small enough and remains clean it can also heal by secondary intention. The longer a wound is open the increased risk of an opportunistic (nosocomial) infection.

Hopefully, with appropriate care the wound will heal without infection. This is the primary goal. However, in spite of the best of care, an occult infection may lead to chronic osteomyelitis. This can take a lifetime of treatment to irradicate.

The bone will unite in a **union, delayed union, nonunion, or malunion**. Hopefully, a well-aligned union will occur. The amount of time necessary for healing varies with different bones, location of the fracture, and most importantly the extent of the trauma. A delayed union occurs when the time to healing goes beyond the expected time but does eventually heal. A nonunion is when the fracture has failed to show adequate healing and fails to progress beyond this stage (usually evaluated with x-rays). A malunion occurs when the bones heal but are angulated or rotated to the extent that it inhibits function.

Bone grafting may need to be considered for the latter 3 events. Autologous bone graft (usually from the posterior iliac crest) is best if needed. The earliest time for placing bone graft is at the second debridement where bone loss with the initial debridement requires replacement for healing. Otherwise, bone grafting may be placed to stimulate a delayed union or nonunion as well to affect bone healing after re-alignment of a malunion.

Rehabilitation of the extremity is an important part of healing. The earlier joint motion, weight bearing, and muscle strengthening can begin the better the overall functional result.

In **conclusion**, treat all open fractures as an emergency. Perform a thorough initial evaluation. Begin appropriate antibiotic therapy in the emergency room and continue for 3-5 days or as indicated. Give Tetanus protocol. Perform initial cleansing, reduction and temporary stabilization in the treatment room and obtain adequate x-rays. Progress to the OR as soon as possible and begin formal debridement using copious irrigation. Stabilize the fracture and x-ray. Readjustment to reduction can be made at this time or on return to the OR. For highly contaminated and traumatic fractures, repeat the debridement in 24 to 72 hours otherwise repeat debridement in 3-5 days. Perform early autogenous cancellous bone grafting if necessary. Give meticulous post op care and affect closure of the wound as early as possible. Rehabilitate the involved extremity.

Fractures of the Femur and Tibia

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FEMUR FRACTURES

Introduction

The femur can be divided into regions when discussing fractures and their treatment. The first of these would be proximal femur fractures including femoral head, neck, and inter-trochanteric fractures. These are discussed in another chapter. Moving distally, the sub-trochanteric region of the femur includes fractures occurring in the metaphyseal region in the first 5cm below the lesser trochanter. Fractures from that point down to the level of the adductor tubercle can be considered diaphyseal shaft fractures. The distal femoral region includes fractures extending into the distal metaphysis and the tibio-femoral articulation. These distal femur fractures can be described as supracondylar femur fractures with or without intra-articular extent.

Femur fractures in adults occur in two major groups of patients. The first group of fractures occurs as the result of high-energy injuries in young adults. These fractures are frequently associated with a variety of associated injuries and these must not be overlooked because of the distraction caused by the obvious femoral deformity. Evaluation of these patients must begin with assessment of airway, breathing, and circulation. If the patient is in hemodynamic shock this is very unlikely to be coming from the femur fracture and a thorough assessment for other sources of blood loss must be performed. Associated orthopaedic injuries include spine fractures, pelvis fractures, hip fractures, patella fractures, ligamentous knee injuries, proximal tibia fractures, and neurovascular injuries.

The second group of fractures occurs as a result of low-energy injuries in elderly patients or patients with a pathologic lesion. Any younger patient who sustains a femur fracture from a low-energy mechanism should be evaluated for the possibility of a metastatic bone lesion, a chronic bone infection, or less likely a primary bone tumor. The basic workup for pathologic lesions is discussed later in this chapter in the section on pathologic fractures. Despite the low-energy mechanism causing these fractures, a workup for associated injuries must be performed as they can frequently be missed.

Diagnosis

Diagnosis of femur fractures is relatively simple as there is usually very obvious deformity associated with these injuries. However, as discussed above, these fractures are often associated with other injuries and evaluation for these injuries is probably the most important part of the work-up. In the casualty department evaluation must begin with assessment of airway, breathing, and circulation.

The circulatory system evaluation includes a good vascular exam of the injured extremity, as vascular injuries can be associated with femur fractures, especially popliteal artery injuries in distal femur fractures. Once again, shock is not usually the result of a closed femur fracture; if patient is hemodynamically unstable, look for other injuries as a cause of the large blood loss. If a vascular injury is suspected, this becomes a surgical emergency, as a vascular repair must be performed in order to save the leg. If vascular repair is to be performed, external fixation of the fracture should be performed at the same time as the vascular repair to align the fracture and protect the vascular repair (see external fixation section below for more detail.)

A neurologic exam of the injured extremity must be performed as nerve injury can occur with femur fractures. This exam should assess for motor function and sensation distal to the level of injury. The motor exam should be compared to the uninjured extremity to compare strength. Often motor strength will be decreased in the injured extremity due to pain, but it is important to make sure that the patient can at least make the muscle groups fire on command.

A good exam of all of the skin on the injured extremity is important to assess for an open fracture. As a good rule, any open thigh wound, no matter the size, with an underlying femur fracture should be considered an open fracture. Often small thigh open wounds are created from the inside out as the broken bone pokes through the skin and then retracts back inside. These small wounds can be very easily overlooked, leaving an underlying open fracture improperly treated. Open fractures must be taken to the operating room as soon as possible to expose the bone-ends and clean them of all foreign material.

Radiographic evaluation should consist of an AP pelvis X-ray, lateral hip X-ray, femur X-rays, and knee X-rays to evaluate the entire femur for fractures and screen for associated injuries such as: fractures and dislocations of the pelvis and hips, patella fractures, and proximal tibia fractures. Prior to obtaining these X-rays it is a good idea to splint the fracture for the patient's comfort.

Treatment

Traction

Generally, treatment of femoral fractures primarily consists of traction to control length, alignment, rotation, and provide patient comfort during healing. In adolescents and adults, split-Russell skin traction is usually inadequate as a maximum of 5kg of traction can be used, and skeletal traction must therefore be used. If able, distal femoral placement of the traction pin is preferred as it applies traction across the fracture site without placing traction forces across the knee ligaments. The distal femoral pin should be inserted from the medial side, in the mid-portion of the bone, at the level of the proximal pole of the patella. This should be just proximal to the flare of the femoral condyles and posterior to the synovial pouch of the knee joint. Start with traction equal to 10-15% of the patient's body weight for skeletal traction. If your hospital has a portable x-ray unit, take films the next day to see if the fracture position is adequate. You may also measure the length of the leg in traction with a tape measure from the greater trochanter to the joint line of the knee. Compare the length of the injured to the normal leg, and if it is more than 1.5 cm short, add a small amount of traction and re-measure the next day. If you use X-rays to determine how much the fracture overlaps, be sure the x-ray is shot at a true perpendicular to the femur or the spatial relationships of the fracture.

Goals of treatment are to correct and maintain length, alignment, and rotation until fracture consolidation, which usually takes approximately 6-8 weeks. Acceptable length is within 2.5cm of the normal side, which can be assessed radiographically or with use of a tape measure. Acceptable alignment is within 20 degrees of posterior bowing or 30 degrees of anterior bowing (the normal femur has a 10 degree anterior bow) and less than 10 degrees of varus or valgus angulation. This is difficult to assess without radiographs. Acceptable rotation is within 15 degrees of the contralateral extremity and generally internal rotation malalignment is better tolerated than external rotation. This can be assessed radiographically by obtaining an AP radiograph of the uninjured hip with the patella pointed straight up and comparing this image to the same image taken on the injured femur. Perkin's traction with the hip and knee both in 90 degrees of flexion can help keep rotation across the fracture in acceptable limits.

Fracture healing in adults takes about 10–12 weeks. By 6–8 weeks, the fracture will show early signs of consolidation. Clinical resolution of pain at the fracture site, lack of instability across the fracture on exam, and radiographic presence of callus formation are all good markers of early fracture consolidation and stability. At this point, it is possible to place the patient in a hip spica cast and begin non-weight bearing ambulation. Middle and distal third femur fractures can be placed in a brace cast with a hinged knee instead of a hip spica. Weight bearing on the injured extremity is usually begun at about 3 months.

External Fixation
External fixation has limited use for definitive fixation of femoral fractures. The indications in which external fixation should be used are as follows: temporary stabilization in the polytrauma patient, severe open fractures with extensive soft tissue damage and contamination, and in the setting of a vascular injury requiring repair. Partially threaded half-pins of 3-7mm in diameter should be placed from the lateral aspect of the femur. These same pins can be placed through the medial subcutaneous border of the tibia as well if the knee joint needs to be spanned. The external connector frame can come from a formal external fixation system consisting of manufactured bars and clamps. However simpler techniques exist such as metal or wooden rods fastened to the pins with plaster of Paris, or the pin-in-plaster technique in which the pins are incorporated into a plaster of Paris cast without any other external frame.

Surgical Management
In many countries, operative fixation of femoral fractures is the treatment of choice. This treatment usually consists of an intra-medullary implant for fracture fixation and is utilized for early immobilization and to shorten hospital stays. However, this technique requires a stock of surgical implants and expertise with placement of these devices. These techniques also usually require intra-operative fluoroscopy in order to safely and accurately place these implants. If available to your hospital, the SIGN nail does provide a method for intramedullary fixation without the need for intra-operative x-ray guidance.
If acceptable alignment (see parameters in traction section above) cannot be achieved or maintained with non-operative techniques, then open reduction and internal fixation may be required. This can be done with use of plates and screws or intramedullary implants.

Key Points for Specific Fractures

Sub-Trochanteric Femur Fractures
These fractures occur in the metaphyseal region in the first 5cm below the lesser trochanter. These fractures are notable in that they can be difficult to reduce. Because the fracture usually occurs below the level of the lesser trochanter, the proximal fragment is usually pulled into a position of flexion by the iliopsoas muscle, external rotation by the short rotators, and abduction by the abductors. As a result, the 90-90 traction position is beneficial in these fractures in order to obtain and maintain acceptable reduction.

Distal Femur Fractures
These fractures involve the distal metaphysis and often can extend into the joint disrupting the articular surface of the distal femur. The distal fragment is often angulated posteriorly due to the pull of the gastrocnemius muscle. Treatment of these fractures usually consists of the use of tibial traction with the knee flexed in order to release some of the deforming force of the gastrocnemius muscle. If the fracture is intra-articular, it is important to align and maintain the articular surfaces to within a few millimeters. If this cannot be done using traction or closed manipulation, open surgical reduction with or without internal fixation is required. Internal fixation, if needed, usually consists of a lateral plate and screws. As stated earlier, it is

important to think about the possibility of vascular injuries with these fractures. As always, a good neurovascular exam is essential in these fractures.

Pathologic Fractures

When a fracture occurs with a low-energy mechanism in a younger patient with otherwise normal bone quality, the concern for a pathologic fracture must be heightened. In younger patients, osteomyelitis is a very common cause of pathologic femoral shaft fractures in Africa. When a patient presents with a fracture and a discharging sinus, surgically debride the fracture and sinus, and obtain deep cultures and a gram stain to help direct antibiotic treatment. Cultures taken in the casualty department from the draining sinus are inaccurate. Unless there is a thick bridging involucrum present on x-rays, removal of the shaft sequestrum will produce segmental bone loss and the result could be disastrous. After debridement, treatment with appropriate antibiotics, nutritional support, and immobilization in traction.

Other causes of pathologic femur fracture include metastatic bone tumors, fungal infection, tuberculosis, and primary bone sarcomas. A chest x-ray, CBC, blood smear, and bone biopsy may help to obtain a diagnosis in difficult cases. Treatment is individualized according to the underlying etiology.

Tibial Fractures

General Principles

Energy of Injury

Tibial fractures are among the most common long bone fractures. They can be isolated, but often are associated with other serious skeletal or soft tissue injuries. A general guiding principle in tibial (and other fractures) is to think about the amount of energy involved in the injury. For lower energy injuries (such as a twisting injury or a fall from standing) there will be significant inherent fracture stability which may allow for less invasive treatment. In contrast, higher energy injuries (such as those sustained in a motor vehicle accident) will be inherently less stable and may require operative treatment.

Level of Fracture

The tibia can roughly be divided into three sections: proximal third, midshaft, and distal third. Each of the three sections has different issues and technical considerations for treatment. The proximal and distal metaphyseal regions are peri-articular, and thus the dynamics of the adjacent knee or ankle joint must be factored in. Additionally, the metaphyseal regions tend to have a more robust blood supply which will aid in fracture union. The diaphyseal (shaft) region, in contrast, has a more tenuous blood supply which may prolong time to union or even lead to non-union. Moreover, significant malunion of the midshaft tibial fracture in the sagittal or coronal plane can adversely affect the function of the ankle and foot.

Soft Tissue Envelope

A major concern with the treatment of tibial fractures is the status of the soft tissue envelope surrounding the osseous structures. A significant portion of the midshaft of the tibial is subcutaneous, which makes open fractures common entities. Open fractures require prompt administration of IV antibiotics if available, traditionally with ceftriaxone and gentimycin. Penicillin is generally added for grossly contaminated wounds Also, the periosteal blood supply to the bone in this region can be easily disrupted leading to potential for non-unions and delayed unions.

Compartment Syndrome

Another important consideration when dealing with closed or open tibia fractures is the concern for possible compartment syndrome. Compartment syndrome occurs when the interstitial pressure is increased within a closed space (a facial compartment), eventually leading to muscle and nerve injury and cell death if left untreated. There are 4 distinct fascial compartments within the leg (anterior, lateral, superficial posterior, and deep posterior). The classic clinical signs associated with a compartment syndrome are:

-extreme pain out of proportion to the injury,
- pain on passive ROM of the toes (stretch pain of the involved compartment):
- pallor of the extremity,
- paralysis,
- paresthesias (early loss of vibratory sensation);
- pulselessness.

It is generally taught that a compartment syndrome is a clinical diagnosis and a surgical emergency, and it must be addressed by releasing the fascial compartments before irreversible damage occurs (classic teaching is within 6 hours).

Proximal Tibial Fractures

Diagnosis

Proximal tibial fractures should be suspected when there is an axial load applied to an extended knee. If there is intra-articular extension of the fracture (tibial plateau fracture) then there will be an accompanying hemarthrosis. Definitive diagnosis is made with orthogonal radiographs of the knee. Although difficult, it is important to evaluate the ligamentous stability of the knee in full extension, as this may affect treatment.

Treatment

Closed treatment can be successfully performed in the proximal tibia, provided there is no significant articular incongruity and no significant ligamentous injury. Following an inital (7-10 days) course of splinting with a posterior long-leg splint with the knee in extension, a long leg cast in extension can be applied. Non-weight bearing should be strictly enforced until there are radiographic signs of healing, usually 6-12 weeks.

External fixation can also be successfully employed to treat fractures of the proximal tibia. The overall principles are the same as cast immobilization. Joint-spanning external fixation is performed with the limb in extension. External fixation can be a temporizing measure to allow for soft tissue swelling to decrease, or can be left in place until union of the fracture is complete. Critical to the success of external fixation for temporary or definitive management is to attempt to maintain length and alignment of the fracture during healing. It is also of utmost importance to maintain clean pin sites; this can be done with daily or BID pin site cleaning.

Internal fixation with plates and screw can also be performed when the necessary implants are available. One of the main benefits of this technique is that it can allow early knee range of motion and thus prevent joint stiffness. However, the technique can be highly demanding depending on the fracture pattern.

Key Points

- Treat non-weight bearing for 6-12 weeks, depending on fracture stability and radiographic signs of healing.

-A primary deforming force on the proximal tibia is the patellar tendon. Maintaining the limb in extension can help to minimize this force.

-Ligomentotaxis can be used to reduce or partially reduce displaced fragments. This is the process by which axial traction is applied to the limb, allowing the ligamentous attachment to the fracture fragments to pull the fragments back into alignment.

Diaphyseal (Mid-shaft) Tibial Fractures

Diagnosis

Diagnosis is again definitively with orthogonal views of the involved tibia, along with xrays of the joint above (knee) and the joint below (ankle) if possible. Associated deformity and swelling can usually be appreciated. It is critical to assess the limb for perfusion and nerve function, especially in the face of severe deformity or displacement. If pulses are not present on intial evaluation in a deformed limb, the limb should be gently reduced into an anatomic position and the re-assessed.

Treatment

Closed treatment can be utilized for the majority of tibial shaft fractures. Fracture reduction followed by long leg cast immobilization in 0-5 degrees of flexion to allow for progressive weightbearing in the cast. More comminuted and displaced fractures have less inherent stability, so weightbearing should progress slower in these fractures. Less that 5 degrees of varus/valgus angulation, 10 degrees of anterior/posterior angulation, 10 degrees of rotational defomity, and <1 cm of shortening is recommended. After 4-6 weeks, the long leg cast may be converted to a cast brace or patellar tendon bearing cast to allow for knee flexion but still control for rotation of the fracture. Average time to union is 16 weeks.

External fixation can also be used for treatment of these fractures, and may be useful when there is significant soft tissue swelling or injury that will require aggressive treatment. Similar treatment protocols can be applied.

Intramedullary fixation can also be utilized if the required instrumentation and implants are available. This is generally accomplished by inserting a metal rod or nail from proximal to distal and then interlocking the nail to control for rotation. If available, they may allow for smaller incisions, faster recover, and quicker return to function.

Key Points

-Always assess for neurovascular status. If there are no pulses, gentle straighten the limb and reassess.

-Compartment syndrome should always be a concern. Do serial exams over time to assess the leg compartments. If there is significant swelling, consider a period of splinting for 5-7 days before casting to allow for swelling to subside.

-Early weightbearing will allow fracture healing to progress more quickly. Stable fracture patterns can progress more quickly than unstable fracture patterns.

-If there is an initial loss of reduction in a cast, the cast may be wedged to allow for adjustments without being removed.

Distal Third Tibial Fractures

Diagnosis

Diagnosis is again made primarily with orthogonal x-rays of the involved extremity, along with x-rays of the adjacent joints above and below. A thorough neurovascular exam is again critical to ensure adequate perfusion to the limb distal to the zone of injury. Intra-articular extension of the fracture should be anticipated and addressed if possible.

Treatment

Closed treatment is possible with relatively low energy, stable fracture patterns. Ligamentotaxis may again be used, as discussed above, to achieve a reasonable closed reduction. It is often necessary to employ a period of splinting to allow for swelling to decrease prior to final casting. Short leg casting may be possible (below the knee); however, if rotational stability is a concern, then extending the cast above the knee is appropriate to help maintain rotational control.

External fixation may be necessary in higher energy, comminuted unstable fracture patterns, or in those with significant soft tissue swelling or injury. This is especially true in fracture which involve a significant portion of the articular surface of the tibia (tibial pilon fractures), where massive swelling is the norm. External fixation of these fractures is typically performed with two alf-pins (5 mm) in the anterormedial tibia, a single transfixion pin through the calcaneous (5 mm), and a single medial pin (4mm) in the medial cuneiform. This final pin allows the foot to be maintained in a neutral position and prevents heel cord contractures from prolonged passive plantarflexion.

Open reduction and internal fixation can also be employed if the necessary implants are available. The general goals of this method of treatment are to maintain length, alignment, and rotation of the distal tibia and fibula in an anatomic or near anatomic position. Specifically it is desirable to achieve and maintain a reduction of the articular surface of the distal tibia in a normal relationship with the talus and distal fibula. Contralateral x-rays of an un-injured distal can help evaluate the adequacy of reduction.

Hip Fractures

Keith Braun, MD

Introduction

Fractures of the hip are common worldwide, especially among the elderly. An increasing number are seen in younger Africans due to motor vehicle trauma. Rarely, hip fractures are seen in the skeletally immature. If left unfixed, fractures in the elderly lead to greatly diminished mobility which leads to pneumonia, bedsores, and death. In the younger adult population, a well-fixed hip fracture results in pain relief and an early return to work. Very few hip fractures are managed non-operatively so it is important that the surgeon correctly identify the best surgical treatment option for each hip fracture patient and perform the operation in a manner that results in a stable hip which is capable of as early weight bearing as possible.

Anatomy

Hip fractures come in two varieties. It is vitally important to recognize this because it has a direct bearing on the choice of treatment. Intracapsular hip fractures (also known as femoral neck fractures) occur within the fibrous capsule of the hip joint. Because the fracture is intraarticular, there is very little blood loss. The femoral head often will lose its blood supply, which crosses the femoral neck, and undergo necrosis. For this reason in the elderly, displaced femoral neck fractures are best treated with a femoral head prosthesis. The other type of hip fracture is extracapsular (also known as intertrochanteric hip fractures). Bleeding in an extracapsular fracture is not constrained by a capsule. The thigh will be swollen and the hemoglobin lower. I prefer the terms intracapsular and extracapsular over femoral neck and intertrochanteric because a fracture of the hip at the base of the femoral neck is actually extracapsular and should be treated as such. Base of the neck fractures should generally not be treated with a prosthetic replacement.

The fracture configuration or geometry, whether it is an intracapsular or an extracapsular fracture, has a bearing on treatment decisions. Intracapsular fractures that are horizontal (parallel to the floor in a standing patient, tend to be more stable. One might consider conservative management for a horizontally oriented intracapsular fracture in an elderly patient, especially if the head fragment is impacted on to the neck and there is no displacement. Minimal internal fixation with percutaneous screws is another option for relatively stable intracapsular fractures. If an intracapsular fracture is vertical (parallel to the long axis of the body) there would be shear forces with weight bearing and the fracture is likely to displace. Operative treatment with a prosthesis is usually the best choice for these fractures.

Extracapsular fractures are evaluated by the number of fracture fragments seen on anterior-posterior and lateral radiographs. Two-part fractures generally have a fracture line extending from the greater trochanter to the lesser trochanter. They are easy to reduce on the fracture table and, when properly fixed, allow for immediate weight bearing. Three-part fractures have a separate lesser trochanter fragment and rely more on the internal fixation for stability. With soft bone or poorly placed implants, three-part fractures can fail with weight bearing. The iliopsoas tendon attaches to the lesser trochanter and displaces it proximally. This reduces the load bearing capacity of the medial side. Don't try to internally fix the lesser trochanter. It probably won't work anyway and will be a waste of time in the operating theatre. A four-part fracture has a head and shaft fragment along with separate greater and lesser trochanteric fragments. The abductors of the hip attach to the greater trochanter and pull it proximally. In a four-part fracture, the surgeon should focus on achieving stable fixation of the head fragment with the shaft fragment and ignore the trochanter fragments. Protected weight bearing, if possible, should be imposed post-operatively on patients with four-part fractures.

Another variety of extracapsular hip fracture is the subtrochanteric hip fracture. The fracture line is distal to the lesser trochanter. This is always an unstable fracture configuration and operative treatment should be carried out in all but the sickest of patients. An intramedullary hip screw results in the most stability for subtrochanteric fractures. Compression hip screws with sideplates often fail in subtrochanteric fractures.

Two words that are commonly used to describe the relationship between hip fracture fragments are "varus" and "valgus". Varus means that the distal fragment is deviated toward the midline of the body, similar to the term, "adduction". For example, if a child has varus at the knee joint, he is bow-legged. Valgus is deviation of the distal fragment away from the midline, like the term "abduction" or like a child that is knock-kneed. In an unstable four-part hip fracture, it is desirable to fix the shaft fragment in valgus relative to the head fragment. This increases the neck-shaft angle and reduces bending forces on the implant.

<u>Evaluating the Patient</u>

With regard to hip fractures, age of the patient is an important consideration. An old patient with an intracapsular fracture does not have to go to the operating theatre in a big hurry. The treatment will most likely be a prosthesis. Viability of the femoral head is not a concern. This patient can be evaluated medically, transfused if necessary, made NPO, and brought to the theatre in the next available theatre opening. Remember, however, that the longer the time from fracture to operative treatment, the more likely there will be pneumonia and bed sores and the more difficult it will be to fix the fracture. A child or young adult with an acute femoral neck fracture or a child with an acute epiphyseal plate separation is a surgical emergency. The fracture should be reduced and stabilized within six hours in order to reduce the risk of avascular necrosis of the femoral head. Extracapsular hip fractures, regardless of the patient's age, are not emergencies but should be fixed as soon as reasonably possible.

The date and time of injury is important to know. Sometimes this is difficult to determine. Rural Africans often do not relate an injury to a specific date on the calendar and have to think about when it happened relative to a farming event, such as planting, or to a weather change. Some hip fractures seen at African hospitals are weeks old. Traditional medicine is often the first line of treatment before the patient is brought to the hospital. Small cuts seen over the greater trochanter are a sure sign that the fracture is old. Bed sores are frequently seen with old fractures. Patients with old hip fractures are generally anemic, poorly nourished, and need a lot more supportive care to achieve a good result.

At many African hospitals, monetary deposits are required before surgical treatment is scheduled. Make sure that the family members know exactly what is required of them and that they are aware of the benefits of prompt surgical care. Do not wait for a deposit in a young patient with an acute displaced intracapsular fracture.
It is important to determine the pre-fracture condition of the patient. A patient who is a "walker, talker, and an eater" is a patient that will generally do well with surgical treatment of a hip fracture. Sometimes hip fracture patients are very sick and elderly. Perhaps they were non-ambulatory prior to the fracture and required a family member to feed them. For these patients, surgical treatment is probably not the best choice. With these patients, it does no good to produce a great looking post-operative radiograph of a fixed hip fracture. First do no harm.

When called to see a hip fracture patient in casualty, you will impress your peers by walking directly to the patient who is lying on the gurney with the involved extremity postured in external rotation and shortened. This indicates a displaced fracture. A patient with a less obvious hip fracture can be diagnosed with a stethoscope placed on the pubic symphysis while tapping on the patella of the injured limb and then comparing the sound to the contralateral limb. There will be a distinct “change of sound” on the fractured side.

Be sure to examine the patient and not just the radiographs. Look for bed sores around the future operative field. Look for the presence of traditional medicine scars or joint contractures which indicate chronicity. Determine the patient’s pre-fracture state of health. Make sure you know whether the fracture is intracapsular or extracapsular and begin to formulate a treatment plan. Make sure the patient has a sufficient hemoglobin level and that blood is available for surgery, especially on comminuted extracapsular fractures. Know the patient’s social situation with regard to finances and the ability of family members to help with care. Find out if the patient is a believer or not and develop a plan to enhance their spiritual health. Write orders that include a Foley catheter and frequent turning. Prepare a clear presentation of the patient for morning rounds or patient management conference.

<u>Surgical Management of Intracapsular Fractures</u>
Most displaced intracapsular hip fractures in the elderly are managed with a femoral head prosthesis. It is different than a total hip replacement in that the implant does not include a replacement socket (acetabulum) of the hip. The prosthetic femoral head articulates with the patient’s own acetabular cartilage. The prosthesis most commonly used is an Austin-Moore Prosthesis (AMP). These are either brought to Africa by visiting staff or purchased new and manufactured in India. They are press fit into the proximal femoral canal and allow for immediate weight bearing.
Pray for the patient. The anesthetist usually gives a regional spinal anesthetic and the patient can be positioned in one of two ways on the regular operating table, depending on the surgical approach. If an anterolateral approach is preferred, the patient is placed in the supine position with a bolster under the buttock of the fractured side. One of the advantages of the anterolateral approach is that the posterior capsule of the hip remains intact and the risk of post-operative posterior dislocation of the prosthesis is lower. This approach should be considered when the fracture is old and the patient has a flexion-adduction contracture or when a patient has a beds ore on the buttock where a posterior incision would be used.

I prefer the standard posterior approach to the hip. The patient is positioned in the lateral decubitus position, as stable as possible, using pillows and straps to keep the pelvis from tilting forward or backward. The region is carefully prepped and draped to allow mobility of the entire extremity. The incision begins longitudinally over the greater trochanter and angles posteriorly toward the midline about 8 cm. The incision does not have to extend distally beyond the greater trochanter. The fascia lies beneath the subcutaneous fat and is thickest directly over the trochanter. I like to use a Cobb elevator to strip some of the fat from the fascia. This helps visualize where the fascia is the best to cut into it in order to expose the deeper structures. It is very important to close the fascia securely and closure is facilitated by the optimal location of the fascial incision. Cutting anterior or posterior to the thickest part of the fascia results in a weak closure. The fibers of the gluteal musculature are split longitudinally. A Charnley retractor is placed.

Below the fascia is a wispy bursa that can be removed with electrocautery, exposing the short external rotators of the hip. In order to see them well, the hip is placed into internal rotation. This also protects the sciatic nerve, which can be palpated in the posterior aspect of the wound. Make sure the blade of the Charnley does not retract the nerve. Divide the short rotators from their insertion into the greater trochanter using electrocautery. The superior tendon will be the piriformis (round, about like a pencil) and the inferior the quadratus femoris. The superior border of the quadratus will bleed, so be sure to coagulate. A Cobb elevator can then be used to peel the rotators from the underlying capsule of the hip. A stay suture can be placed in the piriformis in order to reattach it if desired. The capsule is then opened in a "T" shaped manner. There will be blood under pressure in the capsule. I like to leave the posterior capsule and the labrum intact for reasons I will discuss later.

A corkscrew is used to remove the femoral head. Turn the head so that the fractured surface of the neck is visible. Screw (not hammer) the corkscrew into the neck and head until all the threads disappear. Lever, don't pull, the head out of the socket. In the process, you will tear the ligamentum teres and break an airlock that both serve to hold the head in the socket. Remember how it felt to break the airlock. Debride the remainder of the ligamentum teres from the acetabular floor and irrigate out any small bone fragments.

At this point, measure the diameter of the femoral head and select a prosthesis that best matches the head diameter. If the exact size is not available, chose the next larger size. Insert the head of the prosthesis into the acetabulum using the stem for a handle. Make sure the posterior capsule is not folded in under the prosthesis. Then pull the prosthesis straight out. If it comes out easily without breaking the airlock, try the next size up or down. You should almost be able to lift the patient off the table with the proper sized prosthesis. If you had removed the acetabular labrum and posterior capsule you would lose this important stabilizing function.

Once the prosthetic head size has been determined and a prosthesis is in hand, look in the broach tray for a broach that matches the stem of the prosthesis. Do not make the mistake of using the wrong broach! Using an oscillating saw (don't let the scrub tech hand you an osteotome or rongeur for this step) trim the neck of the femur at a level about one finger's breath from the flare of the superior aspect of the lesser trochanter. It is easy to palpate on the posterolateral aspect of the shaft. If you cut the neck too long, the risk of dislocation increases dramatically because it forces the limb into flexion, adduction, and internal rotation (the position of least stability).

Most of the various prostheses require a neck cut of 45 degrees to the long axis of the femur. This is to ensure that the collar of the prosthesis (also at 45 degrees) is supported evenly by the remaining femoral neck. The superior end of the neck cut will be near the "crotch" or "saddle" between the remaining femoral neck and the greater trochanter. Broach the canal being careful to hold the broach steady with 15-20 degrees of femoral anteversion. In order to determine the anteversion, have the assistant bend the knee to 90 degrees. Imagine the lower leg to be pointing in the 6:00 position. On a right hip, turn the broach so that the short side of the cutting surface points to 9:30-10:00. On a left hip, it would be 2:00-2:30. Placing the prosthesis with the proper anteversion greatly reduces the risk of dislocation. Hammer the proper broach down carefully, especially in the elderly. Stop when the end of the cutting surface is even with the neck cut.

Remove the broach and drive the prosthesis into place being careful not to put pressure on the head and cause it to lose the proper anteversion. Seat the collar of the prosthesis on the cut surface of the neck. Reduce the prosthesis into the acetabulum taking care to prevent the capsule from folding into the joint. If it does, it can be removed with a Kocher clamp. Irrigate the wound. The capsule and the piriformis can be repaired if desired. Carefully close the fascia with heavy suture. Use extra knots. The gluteus musculature can be closed with lighter suture.

<u>Surgical Management of Extracapsular Fractures</u>
Extracapsular fractures are fixed without a femoral head replacement. The main goal is to secure the head and neck fragment with the shaft fragment. This is accomplished with a sliding

lag screw/sideplate device commonly called a Richards compression plating system or a DHS (dynamic hip screw). A fracture table is used to position the patient and reduce the fracture. This special table also allows for fluoroscopic visualization of the reduction process and position of the fixation hardware. The use of the fracture table can be intimidating, especially if parts are missing or broken. A manual may be available with patient setup diagrams. If you need help, the surgical tech will probably know all the tricks and can help you. You, however, have ultimate responsibility for the positioning and safety of the patient on the fracture table. The patient is usually given a regional spinal anesthetic and positioned supine on the table. Pray for the patient. A padded peroneal post is attached and the patient pulled down firmly against it. The foot of the fractured extremity is secured tightly to the traction device and the contralateral limb is placed in a well-leg holder. The C-arm is brought into position before the prep and drape and to make sure the fracture can be seen in both the AP and the lateral projections and that the C-arm operator can smoothly and quickly transition between the two. You have tobe able to see the head on both the AP and the lateral views. Make sure that the images on the C-arm screen are oriented the same as you view the patient. It is very difficult to operate when the C-arm is a mirror image of the patient!

A two-part or three-part fracture can usually be reduced by applying traction, internally rotating the foot and adducting the hip. Using the C-arm in the true lateral projection for guidance, adjust the rotation so that the femoral neck is parallel to the floor. On the lateral view, the angle between the neck and the shaft will appear to be 180 degrees. It will look like the head is straight on the end of the shaft. Four-part fractures are usually more difficult to reduce, often requiring manipulation of the fragments once the exposure is made. Four-part fractures are not for beginning surgeons. Get help!
The lateral side of the hip is then prepped and draped. Be careful to stand away from the drape as it comes up with the C-arm in the lateral view. The lower portion of the drape will not be sterile. Use the C-arm in the AP view to help plan the incision. The proximal part of the incision should be distal to the prominence of the greater trochanter. Don't make the incision longer than you need it by centering over the trochanter. Carry the incision down to the fascia and use a Cobb elevator to remove the subcutaneous fat from the fascia. It will make the fascial closure much easier. Use a large rake to lift the vastus lateralis muscle toward the ceiling. Detach the tendonous portion of vastus lateralis from the inferior aspect of the greater trochanter and continue this incision distally parallel to the floor. Elevate the muscle from the lateral aspect of the femoral shaft and hold it out of the way with a Bennett retractor. Identify the inferior flare of the greater trochanter on the lateral aspect of the femoral shaft.

Select a guide pin and put in on a drill. Make sure that the lag screw reamer slides over the guide pin. Before placing the pin, determine which angle it will be placed. Usually the angle of a normal hip is 135 degrees between the neck and the shaft but sometimes you won't have a sideplate that is 135 degrees. Select the best sideplate for your patient before drilling the guide pin. In most situations, a 135 degree sideplate with 3 or 4 holes is sufficient but this is the sideplate that is often unavailable. If you plan on using a 135 degree sideplate, the complementary angle to the shaft of the femur is 45 degrees. That means that you can tilt the guide pin 45 degrees from the lateral side of the shaft of the femur and it will be correct. Use an angle guide if you need to. Place the C-arm into the AP position. Select a starting point near the flare of the trochanter that will place the tip of the pin in the center of the head. Remember when you positioned the femoral neck parallel to the floor? This is when it pays off. If you hold your pin parallel to the floor and watch the pin go into the center of the head on the AP view, you have a good chance of putting the pin in the center of the head on your first try. Check the lateral to see if you did it. If it is close but not close enough, take a second pin and put it in to correct the error using the first pin as a reference. Be careful not to drive the pins into the hip joint unless the reduction has been very difficult. A pin placed across the joint into the pelvis is then a good thing to prevent it from coming out inadvertently.

What do you do if you do not have a C-arm? Begin with a long prayer and find the most experienced surgeon. Reduce the fracture on the fracture table in the same manner. Expose the lateral aspect of the shaft of the femur a little more completely than normal in order to better see the landmarks, especially the flare of the trochanter. Place a guide pin anterior to the greater trochanter and use it to feel the position and curvature of the femoral head. Drill a guide pin into the neck and head, using your best estimate with regard to its position to a depth of about 90mm. Then place another 2 or 3 pins directed at slightly different angles from the original pin. Obtain an AP and lateral plain radiograph and wait for the films (another good time to pray). Hopefully one of the pins will be adequate, though it is not likely to be perfect.

With the guide pin in place, determine the length of the lag screw. The lag screw should not perforate the hip joint. The lag screw, once in place, should protrude a little bit from the lateral cortex. Using a guide pin of the same length held up against the portion of the pin protruding from the bone, the length of guide pin within the bone can be determined. This can be helpful in selecting a lag screw length. Also, be sure that the lag screw you select is compatible with the large hole in the side plate. The lag screw and the sideplate have to be from the same system and manufacturer. Look at the position of the T-handle on the lag screw driver to make sure the side plate will be pointing down the shaft of the femur once it slides over the lag screw. Ream out a hole for the lag screw with a cannulated reamed adjusted for the length of the lag screw. Watch the reaming on the C-arm. When the reamer is removed, it likes to bring the guide pin out with it. Placing another guide pin in the back of the drill to hold your original guide pin in place while you withdraw the reamer can prevent this. On patients with hard bone, use a tap before placing the lag screw. Check the position of the lag screw in both projections.

Position the sideplate over the lag screw and impact it with a plastic driver against the lateral side of the femur. Then hold it with a Lohman clamp (turkey claw clamp). Screw the sideplate to the femur with appropriate length cortical screws making sure they are too long rather than too short. The screws may be either self-tapping (identified by small cutting flutes near the tip of the screw), or non-tapping screws that require you to tap the holes by hand. Do not use the tap with power but you can place self-tapping screws with power once you get the feel for placing them by hand. Check the screw position with the C-arm. A small compression screw can be placed into the exposed end of the lag screw to compress the fracture site but is rarely used because the same thing is accomplished by weight bearing.

Close the wound by letting gravity hold the vastus in place and placing suture in the fascia.

<u>The Intramedullary Hip Screw</u>
Some surgeons prefer this device for almost every hip fracture in which there is an intact greater trochanter. The incision tends to be smaller, the procedure faster, and the strength of fixation greater (especially subtrochanteric fractures). The procedure is very similar to the placement of a reconstruction-type nail (Russell-Taylor). The positioning of the patient and the reduction of the fracture is identical to that of the sliding hip screw except it is easier if the extremity is adducted as much as possible without loss of fracture reduction. Be slow to use the intramedullary device on fat people or if you are not experienced in using the compression plating system. Do not try it without a C-arm.
Once the patient is positioned, the fracture reduced, prepped and draped, a skin incision is made proximal to the tip of the greater trochanter. The gluteus muscles are split in line with the direction of their fibers and the tip of the trochanter palpated. Some IM (intramedullary) hip

systems are designed to enter the bone in the piriformis fossa and some at the tip of the greater trochanter. Most systems involve reaming of the intramedullary canal and call for a smaller reamer in the distal canal and a larger one in the proximal canal. Reaming is usually done 1 or 2mm larger than the size of the implant. The size of the implant is determined by preoperative templating off of the radiographs.

A driver/targeting device is attached to the implant nail and the nail driven into place. If you set up the patient so that the femoral neck was parallel to the floor, the handle of the driver/targeting device should also be parallel to the floor. Drill a guide pin utilizing the proper sleeves through the targeting hole and watch it go into the neck and head on the AP C-arm projection. Some implants use two head screws, so one has to be inferior in the head and one superior. Check the lateral to make sure the screw(s) will be in the center of the head. Make sure not to perforate the joint with guide pins, drills, or screws. This can be tricky when two screws are placed as opposed to a single centrally located screw. Most IM systems have a means to lock the screw to prevent sliding if desired. To lock the screw or not depends on the geometry of the fracture. One or two distal locking screws can be placed through stab wounds using the same targeting device.

<u>Post Operative Care</u>

Obtain post operative radiographs either off the C-arm or plain films. This ideally should be done with the patient on the operating table or in the PACU. Transfer the patient carefully off of the fracture table or operating table on to the hospital bed. If there is concern about stability or that the patient might get out of bed, use a knee immobilizer on the involved extremity or an abduction pillow. Order adequate analgesics but take care not to over-medicate elderly patients. Use an overhead trapeze, if available, to aid in bed mobility. Check the hemoglobin the next day. Determine the patient's weight bearing status and make this clear to the physiotherapist. Talk to the family about rehabilitation expectations. A radiograph in the clinic is helpful to assess fracture healing in an extracapsular fracture but is generally a waste of money when a prosthesis has been placed. Don't lose track of your real job- let God use you to turn an unfortunate physical ailment into spiritual good.

Both Bone Forearm Fractures in Adults

Rhett Rudolph, MD

Anatomy: The 2 bone forearm consists of a stationary ulna bone that is rotated around in supination and pronation by the radius bone. The ulna at the olecranon makes up the major component of the elbow hinge joint. The radius makes the major articulation point for the carpi at the wrist. The radius and ulna are connected proximally by the annular ligament at the proximal radial ulnar joint. Distally at the DRUJ, distal radial ulnar joint, they are held into position by the triangular fibrocartilage. The radius will rotate to 90° of supination and 90° of pronation from the neutral position of the forearm. Functional supination and pronation(minimal acceptable rotation) is 55° to each direction.

Mechanism of injury: Typically a 2 bone forearm fracture is caused by either a fall on outstretched hand or direct blow from a motor vehicle or motorcycle accident. An isolated fracture of either the radius or ulna is often caused by a direct blow from a blunt object i.e. a nightstick fracture, an isolated ulnar fracture. Because the fall on outstretched hand is usually a rotational injury the fracture is typically an oblique pattern. Direct blows will often cause either a comminuted or transverse fracture depending on the amount of energy supplied to create the fracture.

Initial evaluation: When evaluating a both bone forearm fracture initially assessment of the soft tissues, vascular supply, and bony injury should be performed.

Assessment of the soft tissues should include evaluating peripheral nerve function including the sensory and motor components of the hand. The patient should be asked to make a fist to evaluate the median and ulnar nerve motor function. The patient should be tested in extension of the fingers and the wrist to determine radial nerve function. Abductucion/Abduction of extended fingers is also an excellent test for the ulnar nerve when the radial nerve is intact. Extension of the interphalangeal joint of the thumb is a test for the posterior interosseous nerve. Flexion of the interphalangeal joint of the thumb is a test for the anterior interosseous nerve. The most common area in the upper extremity for compartment syndrome is the forearm.The patient should also be checked for compartment syndrome of the forearm. Pain beyond expected reaction to the extension of fingers passively may indicate compartment syndrome. The firmness of the volar and dorsal forearm should be evaluated. Vascular and neurogenic compromise are late indications of compartment syndrome in forearm injuries. Crush injuries, high-energy trauma, and multiple manipulations of the fracture put the forearm at high risk for compartment syndrome.

X-rays: Anterior posterior and lateral x-rays of the forearm should always be obtained. The x-ray should include both the elbow, the proximal articulation of the radius and ulna, and the wrist, the distal articulation of the radius and ulna. It is necessary to include both joints secondary to the risk of dislocation at these articulations that can cause significant complications if not identified. If there is questionable anatomy as to whether the fracture is present an x-ray of the opposite forearm will oftentimes clarify "normal anatomy". Isolated fractures of the radius or ulna should raise suspicion for dislocation of the opposite bone.

When evaluating the distal radial ulnar joint abnormal widening of the joint would suggest an interosseous injury and/or a radioulnar dislocation. The length of the radius relative to the ulnar head should also be evaluated. On a true lateral of the forearm the position of the ulna next to the radius should also be evaluated to assure that there is no dorsal displacement of the ulna.

When evaluating the proximal radial ulnar joint evaluation of the radial head to the capitellum both on AP and lateral planes should be observed. The radial head should aligned to the capitellum in both planes.

Treatment: A both bone forearm fracture is inherently unstable. The goal of the surgeon in a 2 bone forearm fracture is to align the fracture both in length and rotation to restore normal function and anatomy. If no surgical intervention is available then closed reduction or traction are better options than simple splinting. Fractures of the forearm bones may result in severe loss of motion unless adequately aligned and treated. Even though healing may occur in relationship of the radial humeral, proximal radial ulnar, ulnohumeral, radiocarpal, and distal radioulnar joints if not anatomically aligned will result in functional impairment. The rotational alignment of the 2 bone forearm is influenced by not only the alignment of the bones but the stresses of the pronating and supinating muscles on the bones.

Closed reduction-techniques for closed reduction are based on the position of the fracture. In distal third fractures, the more common position for reduction is distraction and pronation. Distraction can be performed with finger traps and a traction weight around the humerus. If finger traps are not available then clover hitches of 2 inch gauze can be placed on the thumb index finger and middle finger. Counter traction on the humerus can be held by stockinette wrapped around the humerus with the elbow at 90°. The counter traction sling is best placed at about 3 inches proximal to the elbow. While traction is in place the ulna, the most palpable of the 2 bones, is manipulated and reduced. When the fractures seem reduced, a sugar tong splint is well molded across the fracture site. Pressure at the site of the fracture with the heels of both hands pressuring the interosseous space between the bones is a good technique for reduction. X-rays are obtained. Anything less than anatomic reduction should be considered less than adequate. Countertraction is then removed and a sugar tong splint is converted into a well molded long-arm cast. A loop in the cast can be formed at the level of the fracture to support a sling for the cast. X-rays should be repeated at this time. The cast should be molded flat along the level of the ulna to prevent angulation and posteriorly at the back of the humerus/olecranon to prevent distal slipping of the cast.

Pronation for a distal radius fracture theoretically reduces the fracture rotationally because of the forces of the pronator teres proximally. In more proximal fractures, proximal to the insertion of the pronator teres the forearm is reduced and casted in supination secondary to the forces of the supinator and biceps tendon. The mid shaft 2 bone forearm fracture the forearm is casted in neutral.

Relaxation of the muscles is essential for adequate reduction. Bier block anesthesia is an inexpensive, efficient means of relaxation of the forearm. For a Bier block a pneumatic tourniquet is helpful but a reliable blood pressure cuff can be used. An IV is placed in the hand of the affected forearm. The arm is exanguinated of blood using an ace bandage or elastic compression roll. Care in compressing the forearm completely to exanguinate as well as possible is most helpful. The tourniquet is elevated to 250mm/hg of pressure and maintained for at least 20 minutes. 60 milliliters of 1/3% lidocaine (20mls of 1% lidocaine mixed with 40 mls of sterile saline in a 60ml syringe) are then injected via the int. This gives good pain relief and muscle relaxation. The half life of lidocaine is 9 minutes therefore if the tourniquet is left up for 20 minutes the metabolic effects of the lidocaine, possible seizure or cardiac dysrhythmia, are significantly diminished. A reliable tourniquet that can be maintained for 20 minutes is a necessity for safety.

If at all possible some type of fixation is advisable secondary to the instability of casting. If casting is performed, serial x-rays should be performed for adjustments of the cast(wedging) if angulation is present. Only 10° of angulation will begin to cause rotational deficits that will not be recovered. Also because of the instability creating more motion there is a higher incidence of nonunion. Studies by Knight and Purvis, and Hughston showed unsatisfactory results from closed treatment of both bone forearm fractures in 71% and 92% respectively. Unsatisfactory results were either nonunion or loss of functional motion in the forearm.

After casting the patient should be observed for 24-48 hours until the swelling begins to decrease. Neurovascular checks should be performed q.2 hours. If the vascularity of the hand seems compromised the cast should be split both medially and laterally. The patient can be places in a bedside soft traction elevating the hand from an IV pole. The patient is encouraged to move his fingers to reduce swelling.

X-rays should be obtained weekly and compared to the previous x-rays to assure that drifting is not occurring in the alignment. Each film should then be compared to the original reduction. The cast should be changed every 4 weeks till healing is seen.

Traction: Traction has been used as a method of stabilizing the fracture in more adequate alignment. A traction pin is placed through the index and middle metacarpals and the elbow is placed at 90°. Traction of 10 pounds is placed from a soft, wide band of cloth or felt, i.e. a stockinette or felt used for padding in casts. Vascular checks should be performed to assure no compromise is occurring. Long-term, greater than 2 weeks of traction would be difficult to maintain but may be an adequate way to align a fracture that cannot be immediately close reduced and casted.

External fixation: External rotation is difficult, technically and associated with pin infections but in certain situations it may be indicated. Massive soft tissue injury and temporizing a fracture in a distracted position for a temporary fix in the face of multitrauma are two such indications.
Intramedullary fixation: Intramedullary fixation can hold the fracture in adequate alignment. There is an increased risk of nonunion and it is difficult to maintain the radial bow with a straight intramedullary rod. In the absence of a image intensifier (C. arm) opening and alignment of the fracture to permit passage of the rod through the proximal fracture site is usually necessary. The ulna should be nailed first. The fracture should be exposed over the subcutaneous border along the most ulnar aspect of the fracture site. The fracture is reduced with bone clamps and traction. Both ends of the fracture are exposed and can be reamed using a 3.2 drill bit in a retrograde fashion to the proximal bone fragment and antegrade to the distal fragment. In the retrograde reaming of the proximal fragment the drill bit should be used to ream to the tip of the olecranon until it is palpated subcutaneously at the tip of the olecranon. This will allow the placement of an intramedullary rod; flexible titanium nail, Rush rod, Enders rod, or Steinmann pin. The length of the rod can be determined by placing the rod along the external border of the ulna. Final placement of the nail is performed after the radius is aligned and fixed.

The radius is exposed at the fracture site through the appropriate surgical approach. In the mid shaft a volar Henry's approach is usually the preferred approach. In a proximal third fracture a dorsal lateral, Thompson's approach is the preferred approach. Review of these surgical exposures is covered in the technique for plating of the forearm. Fractures of the distal radius are probably not good candidates for intramedullary nailing secondary to the proximity of the insertion site of the nail and potential damage to the fracture site by the placement of the nail through the radial styloid.

Entry point for the nail is at the tip of the radial styloid dorsal to first dorsal compartment. Care should be taken to avoid the radial cutaneous nerve at this level. First the fracture is reduced and held into position using a reduction clamp. It may be necessary to ream the inside of the fracture both proximal and distal first to allow passage of the nail depending on the size of the nail and the radial canal. An attempt should be made to choose a nail flexible enough to maintain the radial bowing but also large enough to resist rotation at the fracture site. Rotation at the fracture site increases the risk of nonunion and malunion. Longitudinal incision is made over the radial styloid and carried down to bone, avoiding the superficial branch of the radial nerve. A hole was then drilled with a 3.2 mm or a 4.8 mm drill through the cortex at the radial styloid. The hole is directed down the shaft of the radius parallel to the cortices and aiming towards the lateral epicondyle. With the wrist in flexion and ulnarly deviated the radial nail is then guided down the canal. Anatomic reduction of the fracture is most helpful to allow the passage of the nail through the fracture without breaking through the fracture site. Serial x-rays or imaging intensifier may be necessary to assure that the radial nail is passed through the fracture distally and into the proximal fragment. The ulnar nail is then passed down the canal of the ulna from the olecranon and through the fracture site to the ulnar styloid. The ends of the pins/rods are bent and buried subcutaneously for removal at a later date. Care should be made sure that neither nail distracts its respective fracture site. Distraction will increase the risk of nonunion.

After the wounds are closed the forearm was placed in a sugar tong splint for 10-14 days. Sutures are removed and the patient was placed in a long-arm cast for approximately 8 weeks. The cast can be removed once union has occurred.

Dynamic compression plating: Ideally displaced fractures of the forearm are treated operatively. This allows anatomic reduction thus allowing improved function. It also increases chances of union. Understandably this technique is not always available to all surgeons in all hospitals. Surgical setup begins with the patient in the supine position. Surgery can be performed either under a regional block or by general anesthesia. The arm is abducted onto an arm board. Sometimes the exposure of the ulna may be easier with the arm draped over the body at 90° flexion at the elbow.

A pneumatic tourniquet is helpful for control of bleeding. The tourniquet may be contraindicated in incidences of significant soft tissue trauma secondary to the further risk of ischemia already sustained by the tissues. Tourniquet time should be limited to no more than 120 minutes. Surgical approach to the radius is accomplished by 2 separate approaches depending upon the area of the fracture. A midshaft to distal fracture is best approached through an anterior approach. This is also the preferred approach for fasciotomies in the event of compartment syndrome. To avoid the more vulnerable neurovascular structures proximally proximal third fractures of the radius or more safely approached from a dorsal incision.

Anterior surgical approach to the forearm: The arm is abducted and the forearm is held in supination. The incision grossly follows the path of the brachioradialis muscle. The incision should be centered over the area of the fracture with approximately 8-10 cm proximal and distal to the fracture. The skin is incised sharply and the brachioradialis musculature is identified. The forearm fascia is opened and incised the length of the skin incision. More distally along the border of the brachioradialis the radial cutaneous nerve may be at risk and should be protected. The interval between the brachial radialis and flexor carpi radialis is identified. Underneath the brachial radialis the radial cutaneous nerve and the radial artery should be identified and protected throughout the case. Traction from the retractors on the radial cutaneous nerve often will cause a temporary injury to the radial cutaneous nerve. Care should be taken to avoid excessive pressure on the nerve during the case. More proximally the supinator attachment to the radius is identified and sometimes is required to be released if the dissection is necessary toward the proximal radius. Also more proximally the radial artery will be found on the bellies of the flexor carpi superficialis musculature. This approach will allow clear access to the bone in the distal two thirds of the forearm at the radius. It also provides to the flat surface of the radius which allows for easier reduction of the radius to assure proper rotation alignment of the fracture. Once the surgeon is down to the bone he/she should stay on the bone to protect other surrounding structures. In closure of the wound the fascia is not closed to avoid compartment syndrome after repair.

The dorsal lateral approach to the radius can also be performed with the patient supine. The forearm is pronated. The incision begins at the lateral epicondyle and grossly follows the path of the extensor carpi radialis brevis toward the base of the second metacarpal in the hand. The length of the incision is determined by the position of the fracture. The dorsal fascia is incised in line with the incision. Gentle dissection is then performed between the extensor carpi radialis brevis and the extensor digitorum communis muscle. This is often done digitally. At times the interval between these 2 muscles is difficult to determine it is more easily determined more distally. Supinator will be found deep to these muscles. The posterior interosseous nerve should be identified 4-5 cm distal to the radial head and should be protected. The supinator is then elevated off the radius. This will give good access to see proximal third of the radius.
The ulna is easily accessed subcutaneously throughout the length of the forearm. An incision should be made along the ulnar border of the ulna 8-10 cm proximal to the ulnar fracture and 8-10 cm distal to the ulnar fracture. It should be noted that the dorsal cutaneous nerve the ulnar nerve is vulnerable to the incision approximately 6-8 cm proximal to the ulnar styloid. The plate can be applied either dorsally or volarly. The tension side is more dorsal. The ulnar nerve is more vulnerable volarly.

Once both fractures are exposed reduction is performed. It is more difficult to reduce the fractures if they are reduced individually. Anatomic reduction of the radius is more essential for pronation and supination. The radius is usually provisionally plated first and then the ulna. Low-contact 3.5 mm compression plates are the standard plate for stabilization of the 2 bone forearm fracture. 6 cortices, 3 holes with bicortical fixation on each side of the fracture is the minimum for stable fixation. The 2 screws closest to the fracture should be compression screws to stabilize the fracture. When possible, interfragmentary screws should be used outside the plate to stabilize butterfly fragments and/or long oblique fracture pieces. Reduction of the fracture can be performed with an indirect reduction technique using the plate itself. Adequate exposure of the fracture site is the key for soft tissue protection and adequate alignment of the fracture.

Postoperatively the patient is placed in a volar splint, below elbow. Depending on the oral eye ability of the patient to follow postoperative orders the volar splint may be removed and gentle range of motion to the wrist fingers and elbow can begin as early as 10-14 days. No weight lifting or significant stress on the fracture should be allowed for 8 weeks. At 8 weeks fracture healing should be assessed before allowing the patient more significant activities. If the patient is unreliable or followup will be difficult a below elbow cast is suggested until healing is seen.

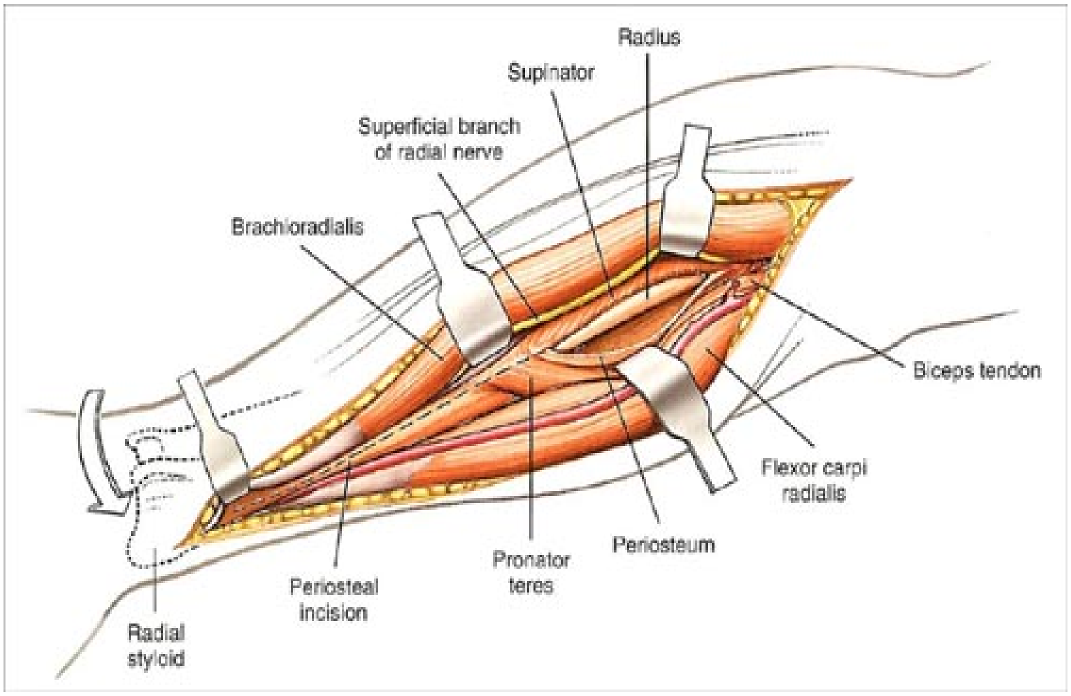
Associated fractures:
Open fractures: Open fracture should be treated immediately upon arrival the patient to hospital. Ideally fixation and also fixation is performed at the same time. The more stable the fixation the less likely the fracture is to go on to infection. External fixation or internal fixation is the ideal.

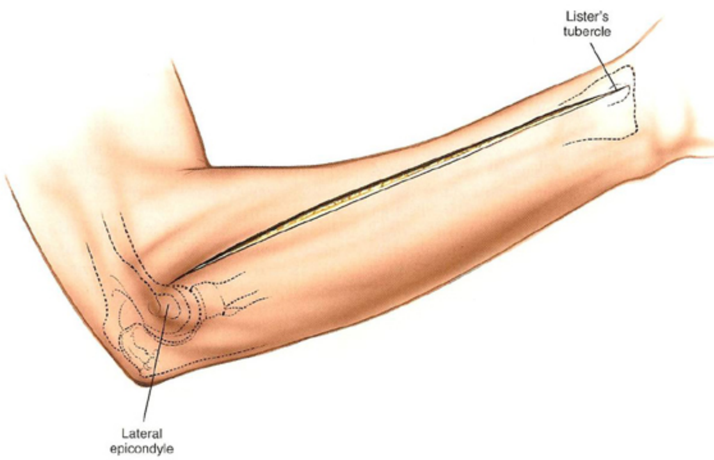
Traction with pins through the second and third metacarpals is also an option of a contaminated wounds.

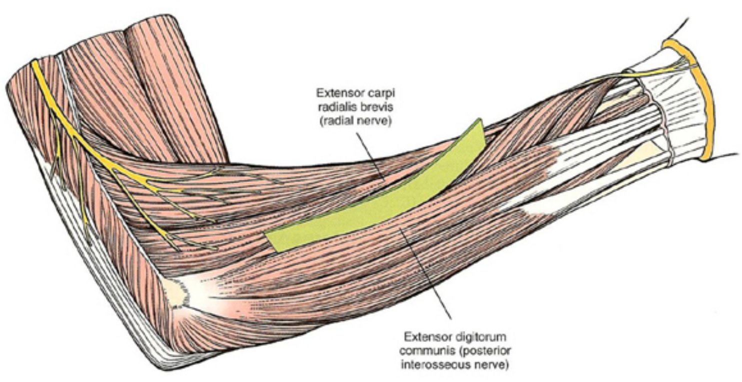
Meticulous attention to detail in handling and treatment of the soft tissues and the bone should always be performed. Paul devascularize tissue including devascularize bone should be excised. Pulse lavage is ideal but copious irrigation by any means is necessary. Surgical extensions of the open wound are closed at the time of surgery whereas the itself can be left open for a second look at 48-72 hours. Definitive wound closure can be performed at this time. Cancellous iliac crest bone graft may be placed for areas of bone loss over severe comminution if closure is possible.

Galeazzi fracture: Fracture of the radius in the distal third of the radius can often times be associated with subluxation or dislocation of the distal radial ulnar joint. Isolated fractures of the radius in this area should raise strong suspicion for a Galeazzi type fracture. A true lateral x-ray of the forearm should be performed to assure that the distal radial ulnar joint is intact. The most common cause for a missed Galeazzi fracture is inadequate x-rays. Stable internal fixation of the radius oftentimes will reduce the dislocation. After fixation, the wrist should be supinated and pronated to assure that the distal radial ulnar joint is reduced and stable. If the joint is stable the patient should be immobilized in supination. If it is not the distal radial ulnar joint should be pinned in reduction with a 0.062 K wire from the ulna to the radius. The forearm should then be also casted in supination for 4 weeks. The pin is removed at 4 weeks. On occasion the distal radial ulnar joint cannot be reduced. Open reduction of the joint removing soft tissue from the joint space is necessary at this time. Flexor carpi ulnaris has been reported as the offending tendon in soft tissue interference of joint reduction.

Monteggia fracture: Fracture of the proximal ulna with a dislocated radial head is called a Monteggia fracture. Again adequate AP and lateral x-ray of the proximal forearm with good visualization of the elbow joint is necessary for preoperative evaluation. Anatomic reduction of the ulna typically will reduce the dislocation of the radial head. When an isolated fracture of the ulna is seen on x-ray it is strongly advised that the radial head should aligned with the capitellum both on AP and lateral planes. In children closed reduction of the ulna is often possible. In adults closed reduction is much less likely. Bleeding or intramedullary fixation of the ulna should be performed. After fixation of the ulna the elbow should be placed through a full range of motion both flexion extension and pronation and supination of the forearm to assure her stability of the radial head. X-rays or an image intensifier should be used to confirm the reduction of the radial head. As with the Galleazzi fracture if the radial head is not reducible reduction through a posterior lateral approach may be necessary. Soft tissue interposition or fracture pieces of the radial head may be the source of block of reduction.


Radius
Supinator
Superficial branch
of radial nerve
Brachioradialis
Biceps tendon
Flexor carpi
radialis
Periosteum
Pronator
teres
Periosteal
incision
Radial
styloid


Lister's
tubercle
Lateral
epicondyle


Extensor carpi
radialis brevis
(radial nerve)
Extensor digitorum
communis (posterior
interosseous nerve)

Compartment Syndrome

Douglas W. Lundy, MD, FACS

Compartment syndrome is one of the very few true emergencies in orthopaedic surgery. Previously, femoral neck fractures, talar neck fractures, open fractures and unreduced dislocations were considered emergencies in most situations. These conditions are truly orthopaedic urgencies but not necessarily emergencies that would result in loss of life or limb. These other conditions must be fixed as quickly as possible, but compartment syndromes must be treated in an emergent basis. Delays in treatment may well result in amputation of the leg.

A good definition of compartment syndrome is “Increased pressure within a limited space [that] compromises the circulation and function of the tissues therein, resulting in tissue ischaemia, necrosis and nerve damage.”[1]

Compartment syndromes are rare with an incidence of 3.1/100,000 persons. Compartment syndromes are more common in men (incidence for men: 7.3 per 100,000 and incidence for women: 0.7 per 100,000[2]). The most common injuries resulting in compartment syndrome are diaphyseal tibial fractures (36%) and soft tissue trauma (7%). Other mechanisms include arterial injury, crush syndrome, prolonged immobilization, envenomation and burns. The actual incidence after tibial fractures is around 7%[2].

Pathophysiology

Compartment syndromes are caused by an Insult to normal tissue homeostasis in a compartment leading to increased tissue pressure,reduced capillary blood flow, local tissue hypoxia and local tissue necrosis. The causes for this insult vary and may occur by:

- Increase the contents of the compartment.
  - Hemorrhage
  - Edema
- Decrease the volume of the compartment.
  - Tight dressings/casts/splints
  - Fascial closure
  - Localized external pressure
- Metabolic insults that disrupt the microvasculature.
  - Revascularization phenomena

Is a patient younger than 35 with a tibial fracture more likely to have a CS than a patient over 35 years of age? Actually, this is true. People less than thirty-five are three times more likely to get a compartment syndrome than older people. The cause for this is unclear.

Diagnosis

The diagnosis of compartment syndrome is often very clear, but at times it may not be very evident. Many providers mistakenly assume that there is no compartment syndrome because the patient may be able to move their toes or have intact pulses. Compartment syndrome can be evolving in this case, and these signs may not be present until the later stages when surgical management will provide limited if any benefit.
The six “P’s” of compartment syndrome are:

1. Paralysis
2. Pallor

3. Pulselessness
4. Pressure
5. Paresthesia
6. Pain out of proportion

Pain is the most sensitive sign in diagnosing compartment syndrome and may be the first sign present. Some believe that paresthesias may be the first sign in many cases. These signs are not highly specific since many people presenting with high-energy tibial fractures will describe pain and paresthesias. “Pain and aggravation of pain by passive stretching of the muscles in the compartment…are ***the most sensitive*** (and generally the only) clinical findings before the onset of ischemic dysfunction in the nerves and muscles”[3]. It is interesting in that the positive predictive value of the clinical findings was 11% to 15%, but negative predictive value (provided by the absence of the signs is 98%[4]. This means that “the clinical features of compartment syndrome are ***more useful by their absence in excluding the diagnosis*** than they are when present in confirming the diagnosis.[4]”

What exactly is pain out of proportion?

Pain is highly subjective. To know what pain is proportional, one would have to know how much pain a certain injury generally produces. To determine this, one would need to see many similar injuries and then the requisite experience would enable the examiner to more confidentially diagnose compartment syndrome. The surgeon must always err on the side of caution; that is if the surgeon suspects a compartment syndrome, strong consideration should be given to proceeding with fasciotomy rather than continued monitoring.

Pressure measurements have developed into a very popular method of “diagnosing” compartment syndrome. The surgeon should always remember this principle – That **compartment syndrome is a clinical diagnosis and that pressure measurements should only be considered as part of the clinical picture.**

Please remember that pressure measurements are not required to diagnose compartment syndrome, and most orthopaedic trauma surgeons do not routinely measure compartment pressures. There are several techniques to measure compartment pressures: Whitesides’ method, STIC monitors and arterial pressure monitor. The pressure should always be measured by an eighteen gauge needle.

In the past, absolute pressure measurements of 30 mm Hg or 40 mm Hg were considered to be diagnostic, but this is no longer the case. If the pressure is measured, most surgeons now employ the “delta *p*” technique. The formula is as follows:

Δp = Diastolic BP – Compartment Pressure.

For instance:
18 (Δp) = 80 (DBP) – 62 (Comp P)

If Δp is less than 30 mm Hg (as it was in the illustrated case above), the surgeons should consider fasciotomy. This implies that the pressure within the compartment is so high that the blood pressure is insufficient to provide adequate oxygenation of the tissues. Remember though, pressure measurements are not necessary to diagnose compartment syndrome. Several studies have demonstrated cases where patients with Δp of thirty never manifested a compartment syndrome further emphasizing the clinical diagnosis[5,6]. “Clinical assessment is still the diagnostic cornerstone of ACS (acute compartment syndrome)”[7].

A big concern for compartment syndrome is the people who are unable to report the presence of extreme pain. Patients with closed head injuries with loss of consciousness, spinal cord injuries and/or peripheral nerve injuries and patients on drugs may not be able to notify the surgeon of “pain out of proportion”. In this situation, the surgeon must be especially attentive to the possible presentation of a compartment syndrome and perform early fasciotomies if indicated.

What about lab tests? Creatine kinase, myoglobin and fatty acid-binding protein all go up with compartment syndrome, but none of these are specific enough to differentiate from trauma[7]. Laser Doppler Flowmetry has never been shown to be useful in diagnosing compartment syndrome. Near-Infrared Spectroscopy may be promising, but needs more investigation.

Open fractures are especially prone to develop compartment syndrome. Many find this surprising since they assume that the fascia surrounding the muscle was torn during the injury causing the open fracture and think there is less chance of a compartment syndrome developing. Studies have shown however that the more significant open fractures are actually at a higher risk of developing compartment syndrome. The incidence of compartment syndrome was found to be directly proportional to the degree of injury to soft tissue and bone; this complication occurred ***most often in association with a comminuted, type-III open injury to a pedestrian***[8]***.***

Physical examination of compartment syndrome is critical. Most examiners view the entire clinical picture when evaluating for compartment syndrome. Pain with passive extension of the affected compartment is carefully evaluated. Passive dorsiflexion of the ankle and toes extends the muscle-tendon units of the superficial and posterior compartments of the leg placing them in a stretched position. If the patient’s pain is substantially worsened by this maneuver, the examiner may be more strongly convinced that the patient is in the midst of a compartment syndrome. Likewise, passive plantarflexion of the ankle will passively extend the anterior and lateral compartments of the leg worsening the pain associated with compartment syndrome of these structures. Other signs to look for are the other 6 P’s: Paralysis, Pallor, Pulselessness, Pressure and Paresthesias. Interestingly, studies have shown that residents are unable to consistently diagnose compartment syndrome by the perceived firmness within the affected leg[9].

Treatment

Clearly, the only acceptable treatment of compartment syndrome is fasciotomy of the affected compartments. No other course of treatment is able to reduce the pressure and ischemia within the compartment. Interestingly, many patients with compartment syndrome worsen if the elevate the affected extremity.

In the leg, the fasciotomy incision(s) are made in longitudinal fashion down both sides of the leg. Make your incisions long and generous – do not be concerned with the cosmetic appearance of the leg. Surgeons experienced in the treatment of compartment syndrome can often release the compartments through a single lateral incision, but the two incision technique is probably best for surgeons who are less experienced in this condition. Attached documents and videos describe how to perform a fasciotomy.

After the fasciotomies are complete, the best way to care for the wound in negative-pressure wound therapy with a vacuum sponge technique. The negative-pressure wound treatment helps decrease edema within the wound and even helps keep the wound from spreading excessively. The wounds are occasionally able to be closed five to seven days later, but the wounds require split-thickness skin grafts most of the time. In some situations, the wounds can be definitively treated with dressing changes watching the wound granulate and epithelialize over time.

Missed compartment syndrome or late presentation of compartment syndrome

Unfortunately, compartments syndromes are missed by physicians for to many reasons. In Africa, patients may not be able to come to the hospital for days after an injury, and by the time they present, the compartment syndrome has run its course.

The long term sequelae of untreated compartment syndrome are at best a scarred contracted extremity with limited function. At worst, the limb is necrotic and requires amputation for the person to survive the inevitable sepsis and myoglobinuria and renal failure that will result.

If a patient presents with a compartment syndrome that has already transpired, experts are divided as to how to proceed. Certainly, if the limb is nonviable and causing massive problems due to sepsis and renal failure from myoglobinuria, immediate amputation is critical for the survival of the patient. If the limb is salvageable with minimal risk to the patient, the surgeon should consider saving the extremity. The limb should be splinted in a position of function to allow for the compartments to scar down in a more reasonable position.

The question regarding performing fasciotomies in the late presentation of compartment syndrome is controversial. Fasciotomies could possibly help with reducing whatever pressure is still present thus limiting additional muscle damage, but fasciotomies may result in allowing infection to occur. In some situations, the affected leg is best left alone and splinted in appropriate functional position. Early tenotomies (cutting contracted muscle-tendon units) will help in producing more functional limb[10].

The legal system in the United States and other developed countries results in significant liability for surgeons who miss a compartment syndrome. As the malpractice system in Africa develops, surgeons should learn from their colleagues in the United States and Canada how to avoid these claims. Clearly, communication with the patient is the most critical component when treating a missed compartment syndrome[11]. In one study[11], increasing time from the onset of symptoms to the fasciotomy was associated with an increased malpractice payout ($p < 0.05$). A fasciotomy performed within eight hours after the first presentation of symptoms was uniformly associated with a successful malpractice defense. In another study, a hospital mandated better record keeping. “We have instituted for our residents, nursing staff, and faculty an educational program on the documentation of compartment syndrome in patients who are at risk for this condition.”[12]

Summary

1. Document well! This includes stating signs and symptoms present and absent, as well as decision process.
2. Remember – compartment syndrome is **a clinical diagnosis**.
3. Consider releasing fascia within 20mm to 30mm of DBP*.
4. Be especially careful in the head injured, asensate and chemically impaired patients!

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Non-union of Long Bone Fractures

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When a bone is fractured, it heals with progression through the following stages after the initial traumatic impaction: inflammation, soft callus formation, mineralization and hard callus formation, and remodeling and repair. This process does not occur uneventfully in 5-10% of fractures. Any fractured bone about the skeleton can progress to a non-union, but this chapter will focus on the non-union of long bones. It will outline some general principles that can be applied to the management of this difficult problem in addition to some specific treatment guidelines.

Fractures about the diaphysis of a long bone without adequate healing are generally considered delayed unions around three months and ununited between three and nine months from the date of injury. The diagnosis of a non-union is not one solely based on radiographs but is one that is arrived at with the addition of a sound history, physical examination, and sometimes laboratory values. Important things to elicit from a history include the mechanism of injury, whether the fracture was open or closed, extent of soft-tissue injury, fracture pattern, presence of pain at the fracture site, ability to bear weight, recent use of non-steroidal anti-inflammatory drugs or steroids, nutritional status, and a history of smoking, diabetes, or immunocompromise.

The clinician should find out whether the fracture was treated surgically with fixation or nonoperatively with a cast, splint, or orthosis. If a fracture is treated operatively, it is important to know what kind of implant was used and whether the goal was absolute or relative stability as knowledge of both factors aid in the assessment of fracture healing on imaging. To attain absolute stability, rigid fixation in the form of compression plating or interfragmentary lag screw fixation is applied. The fracture then heals via primary or direct bone healing, which is often difficult to appreciate on plain films, represented by often subtle bridging trabeculae and healed cortices across the fracture site. With relative stability, flexible fixation is used and includes nonoperative management, external fixation, percutaneous pin fixation, intramedullary nailing, locked plating, and dynamic compression plating when used in a bridging or buttress mode. Fractures treated this way heal via secondary or indirect bone healing and the presence of callus formation, if present, can be easily appreciated on imaging.

On exam, the simplest way to detect a united fracture is the absence of pain with percussion at the fracture site. This usually corresponds with the lack of a subjective complaint of pain. Serial, orthogonal plain radiographs should be obtained until confirmation of union. Characteristics on x-ray supporting a non-union include the absence of bridging bone across the fracture site and persistent fracture lines, sclerosis along the fracture edges and across the medullary canal, and lack of callus formation. If it is unclear whether a fracture is united, computed tomography is the gold standard to detect bridging bone and callus across at least three cortices in the axial, coronal, and sagittal planes. One should also be cognizant of the possibility of a pathologic fracture in the setting of a delayed or non-union if the fracture is not healing despite good biology and stability or if it seems to be healing in an irregular fashion.

As described below, infection can contribute to the inability of a fracture to heal. Patients often complain of persistent pain, even at night and at rest and sometimes associated with fevers. Open fractures carry a greater risk of infection and patients may or not have any wound complications, including erythema, drainage, and tenderness. Inflammatory markers, including a white blood cell count with differential, erythrocyte sedimentation rate, and C-reactive protein, may be elevated in the setting of an infected non-union. These values should be interpreted carefully as they can be elevated in the postoperative period, infection elsewhere around the body, and with systemic inflammatory conditions including rheumatoid arthritis. Malnourishment can also contribute to a poor healing response and possibly infection and can be monitored by measuring a total lymphocyte count and prealbumin level.

Bone graft has a role in the management of non-unions. Bone graft is broadly divided into autograft and allograft. It is further classified as being osteogenic, osteoinductive, or osteoconductive and may exhibit more than one of these properties. Osteogenic grafts contain mesenchymal stem cells with the hope of differentiation along osteoblastic lines, for example iliac-crest bone graft or that obtained via bone marrow aspirate. Osteoinductive graft contains growth factors (i.e. vascular endothelial growth factor, platelet derived growth factor, transforming growth factor-B) that stimulate bone formation and vascularity, for example that found in the bone morphogenic protein family. Osteoconductive grafts serve simply as a structural scaffold upon which bone can be laid and include cancellous and cortical allograft.

Simply put, when thinking about delayed osseous healing, it is either the quality of the fracture biology (i.e. vascularity, soft-tissue envelope), quality of the reduction and immobilization or fixation, or both. Non-unions are classified as one of three types, hypervascular or hypertrophic, oligotrophic, and avascular or atrophic. Infection can be a concomitant finding and contributing factor to an ununited long bone fracture. The appropriate classification of a non-union and discerning the presence of infection guides operative and medical management. Hypertrophic non-unions suffer from inadequate stability or fixation, while atrophic non-unions suffer from a compromised biologic environment around the fracture.

Hypertrophic non-unions result from excessive motion at the fracture site from inadequate stability with operative fixation or premature weight-bearing. The fracture inherently has a preserved vascular supply, evidenced by the presence of exuberant callus on plain films. This abundant callus at the ends of the fracture fragments on x-ray is often described as having a “horse-hoof” appearance. The goal of surgical management is to apply more rigid fixation to the fracture site and achieve enhanced stability. Typically, this is done so with compression plating. The callus at the fracture ends does not have to be debrided as it has the capacity to mineralize into mature bone but often is because it blocks apposition of the plate to the surface of the bone. In the presence of a united fracture with a residual angular deformity (a malunion) the callus should be excised and the bone reduced and fixed in the proper alignment in the coronal and sagittal planes. In the scenario where a fracture of the diaphysis of a long bone was treated nonoperatively, a reamed intramedullary nail can be placed with hopes of an interference fit and thus more stability at the fracture site. Sometimes, a long bone can go onto a non-union despite the presence of an intramedullary implant. In this scenario, the nail may not adequately fill the medullary canal and an exchange, reamed intramedullary nailing with a larger diameter implant may be warranted. Reaming disrupts the endosteal blood supply (2/3 of a bone’s blood supply with the periosteal circulation accounting for 1/3) but this recovers around six weeks and reaming deposits cancellous autograft and mesenchymal stem cells at the fracture site, further supplementing the preserved vascularity and osteogenic potential of the fracture. Nailing offers the advantage in the lower extremities of early or immediate weight-bearing whereas plates are usually protected for a variable period of time. External fixation is also an option in an unstable fracture that has failed closed management. With regard to bone graft, structural autograft or allograft may be required to improve stability and may include devascularized fibular strut grafts or cancellous allograft.

Oligotrophic non-unions have hypertrophic and atrophic characteristics. They do not have callus on x-ray but have a presumably intact blood supply. They can occur after major displacement of a fracture after reduction or fixation. For example, distraction of a fracture can occur with intramedullary nailing of a femur (can also occur with plate fixation of long bones), leaving the fracture ends without bony apposition. The fixation may be stable enough, but healing cannot occur without contact between the fractured bone ends. The solution includes repeat reduction in the case of nonoperative management or revision fixation (i.e. exchange intramedullary nailing). Dynamization of an intramedullary nail in the femur or tibia is also an option to allow for compression of the fracture ends around the nail and involves removing the distal, statically interlocked screw and allowing immediate weight-bearing. In the setting of bone loss and potential shortening with fracture reduction, intercalary, structural autograft or allograft may be necessary.

Atrophic non-unions are the result of a poor biologic environment and compromised local vascularity. While radionuclide scans are "hot" and show increased uptake with hypertrophic and oligotrophic non-unions, atrophic non-unions are "cold." These non-unions are often seen in open fractures, especially about the tibia, where the periosteal blood supply is disrupted as the bone is ejected through a thin, tenuous soft-tissue envelope. Systemic conditions are often contributory, including chronic steroids and immunosuppression or immunocompromise, renal disease, history of irradiation, malnutrition, and smoking. Diabetes is not directly associated with atrophic non-unions but these patients should have strict monitoring of their glycemic state, meticulous care and preservation of their soft tissues, and should have their weight-bearing protected longer with plate osteosynthesis of the lower extremities. Plain radiographs show no callus or bridging trabeculae and osteopenic or sclerotic bone ends. They may have rigid, stable fixation in place, but the healing potential of their fracture is poor. These patients should be managed with open debridement of the fracture site back to bleeding trabecular bone and vascularized autograft (including iliac crest or fibular graft) and/or osteogenic or osteoinductive allograft. The fixation applied during the secondary procedure can be similar to that placed in the index surgery. For example, in a previously open, ununited tibia fracture with plate fixation, a plate rather than an intramedullary implant should be applied to preserve the potential endosteal blood supply. A common misconception is that comminuted fractures inevitably have a poor bloody supply and healing capacity. In fact, in a closed fracture, the comminuted fragments may have relatively well-preserved vascularity depending on the injury to the surrounding soft-tissue envelope. Bridge fixation in the form of an external fixator, spanning plate, or intramedullary nail with protected weight-bearing can often lead to union.

Infection can complicate and contribute to non-unions. With a deep infection, barring bacteremia or sepsis, ideally the hardware should be left in place in an unstable fracture to achieve healing prior to removal. In an infected non-union, the patient should undergo removal of hardware, eradication of any biofilm, and multiple irrigation and debridements with empirical or culture-specific antibiotics until all wounds and the fracture site are clean and intraoperative cultures are negative. To preserve length and gain local control, cement nails, spacers, or beads impregnated with thermostable antibiotics including vancomycin, tobramycin, and/or gentamicin can be used. After hardware removal, reduction can be held with splint or cast immobilization or an external fixator. Resolution of infection, and the decision on when to proceed with reimplantation, can be monitored with negative intraoperative cultures, clinical exam, improved pain, and serial inflammatory markers. External fixators all experience some sort of infection eventually, including local disease at the pin sites, if left in place for an extended period of time, usually around the six-week mark. If the decision is made for internal fixation or an intramedullary nail after initial external fixation, the patient should have a "pin holiday" for a few weeks after removal of the pins and should probably receive a course of broad-spectrum antibiotics.

Recently, much study has been devoted to the use of low-energy pulsed ultrasound, a form of bone stimulation, in the treatment of delayed unions, non-unions, and even acute fractures. This technology relies on piezoelectricity to produce and transmit high-frequency acoustic pressure waves into the body by molecular vibrations and collisions. It has been shown clinically to enhance bone repair, thus speeding up healing. Varying mechanisms of action on the local osteoblastic environment have been theorized, including an increase in cellular proliferation, increased collagen and protein synthesis, enhanced membrane permeability, microscopic fluid shifts and shear stresses on osteoblasts, and the alteration of voltage-gated sodium and calcium channels. Application typically involves twenty minutes per day of transdermal use. Future directions will involve the marriage of ultrasound with various methods of fixation and bone graft substitutes to find the ideal combination for various fracture patterns around the body.

Non-unions of long bone fractures can be a difficult problem for orthopaedic surgeons. The treating surgeon must not only treat the ununited fracture but must also coordinate the total care of the patient. This often involves a multi-disciplinary approach to optimize a patient’s medical condition, including nutritional, endocrine, and infectious disease health, to give an ununited fracture the best chance of healing with treatment. The hallmark of non-unions is that they will not heal without intervention. Hypertrophic non-unions enjoy hearty cellular and vascular activity at the fracture site but have inadequate fixation and stability. Atrophic non-unions lack the full capacity for cellular healing along the endosteal and periosteal bony surfaces. With atrophic, oligotrophic, and hypertrophic non-unions, treatment is bone grafting and/or internal fixation, or noninvasive treatments. Infection can be quite a confounding variable and must be eliminated prior to definitive management.

Malunion of Ankle Fractures

Volker Roth, MD

Malunion of ankle fractures

Introduction	Ankle fractures are beside wrist fractures the most common fractures that require trauma care. In the absence of medical infrastructure the patient may rely on traditional bone setters or other forms of traditional treatment or may neglect the fracture. In case of a simple lateral malleolar fracture the outcome may be fairly good. In case of bimalleolar fracture, comminuted fracture, syndesmosis disruption and fracture dislocation malunion of the ankle fracture may result. The patient will present with a painful swollen ankle, often with marked hindfoot valgus and lateral rotation (lateral tilt). Weight bearing may be painful or impossible. The restrictions in the daily life of the patient are numerous. As the lateral malleolus is the cornerstone of ankle stability and function any malunion of the fibula changes the biomechanics of the joint. The most common presentation of a malunited ankle fracture shows: ➢ a shortening and external rotation of the distal fibula, ➢ a widening of the ankle mortise and ➢ a lateral tilt of the talus If the patient presents late, he may have developed a posttraumatic flat foot, arthritic changes and contractures. When dealing with such a patient you should evaluate the following factors that might influence your treatment plan: 1. *Injury factors:* What type of fracture has occurred? The malunion led to what kind of deformity? Is there left a rest of ankle function? Is there any sign of infection? Has the patient an impaired bone quality? 2. *Patient factors:* What are the activities of the patient? How is he earning his livelihood? Is he able to understand and follow the rehabilitation instructions (cast, none or partial weight bearing)? Is he better off with an orthopedic shoe? 3. *Institutional and personal factors:* Does your hospital dispose of the necessary orthopedic implants and OR infrastructure (see equipment list)? Is your surgical team capable to plan and carry out the surgical procedure? Can you offer the service of an orthopedic shoemaker? With this factors cleared, you should be able to propose a treatment plan to your patient and his family. Take time to make clear that you will not be able to restore a normal ankle. The treatment goal is to correct the deformity, to enable weight bearing, to reduce pain and to slow arthritic changes. Talk about complications as: infection, delayed union and pseudarthrosis as well as postoperative pain and swelling.

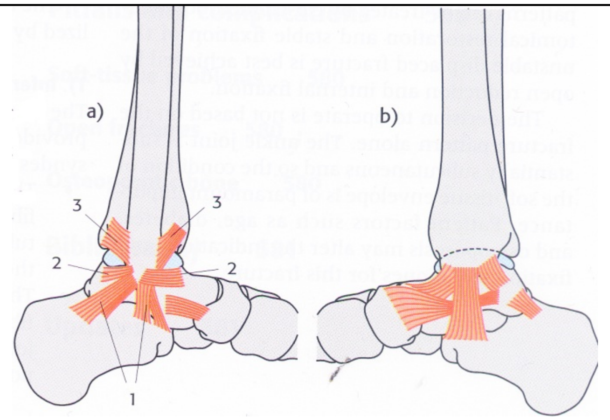
<table>
<tr>
<td>Ankle anatomy</td>
<td>The stability of the ankle mortise depends both on the bone configuration and the osteoligamentous system:
➢ The ankle mortise consists of the articulation of the distal tibia, the distal fibula and the saddle-shaped dome of the talus. The talus has important medial and lateral joint surfaces that articulate with the respective malleoli.
➢ Just above the ankle joint space the fibula is fixed in the incisura tibae (tibial notch) by a strong ligamentous structure, the syndesmosis with three parts(Fig. 5.1 a No. 3):</td>
<td>

Fig. 5.1 a Lateral ligament complex, b medial ligament complex © AO Publishing</td>
</tr>
<tr>
<td>Ankle anatomy</td>
<td colspan="2">• the anterior tibiofibular ligament, from the anterior tibial tubercle (Tubercule Tillaux-Chaput) to the distal fibula,
• the posterior tibiofibular ligament, from the posterior tibial tubercle to the distal fibula and
• the interosseous ligament from the tibial notch to the distal fibula in continuity with the interosseous membrane
➢ Collateral ligaments prevent varus and valgus tilt of the talus in the ankle mortis:
the lateral collateral ligaments (anterior and posterior talofibular ligament Fig. 5.1 a No. 2 and calcaneofibular ligament Fig. 5.1 a No. 1) and
the medial collateral ligament (deltoid ligament) Fig. 5.1 b</td>
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</table>

The uninjured ankle shows the following details on a 20° internal rotation ap view ('mortise view'):

- The joint space (Fig. 5.2 No. 1) is of equal width central, medial and lateral. The joint axis is perpendicular to the longitudinal axis of the tibia.
- The talus is without tilt and has an equal joint space at the medial and lateral malleolus.
- The Shenton's line (Fig. 5.2 No. 3) indicates the correct relation between the joint line of the fibula and the distal tibia. It is uninterrupted. A spike at the fibula points to the tibial joint line (Fig. 5.2 No. 2).
- Due to the tight relation of fibula and tibia in the tibial notch we observe a tibiofibular overlap (Fig. 5.3 No. 2) of 3-5 mm at the level of the syndesmosis. The space between tibia and fibula (clear space Fig. 5.3 No. 1) measures ≤ 5 mm. Both are indicators of an unruptured syndesmosis.

The above mentioned landmarks of an ap ankle X-ray (in 20° internal rotation) allow judging the anatomic position of the joint partners and the stability of the ankle mortise.

In case of a fractured ankle:

- the landmarks give information about the involvement of the syndesmosis and
- allow to judge the stability of the medial collateral ligament.

In case of a malunited ankle fracture the landmarks guide preoperative evaluation and planning as well as the intraoperative correction.

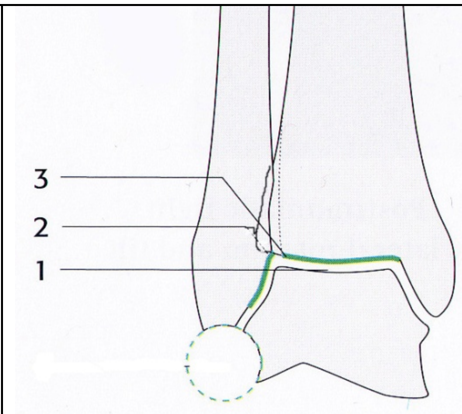

Fig. 5.2 normal ankle anatomy © AO Publishing

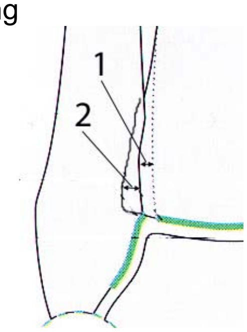

Fig. 5.3 Tibiofibular overlap (1) and clear space (2) at the syndesmosis level

<table>
<tr>
<td>Biomechanics of ankle injuries</td>
<td colspan="3">To understand the natural course of a malunion of an ankle fracture, you need a basic understanding of the biomechanics of ankle injuries and the most used classification (AO-Classification). The fractures are classified according to the relation of the fibula fracture to the syndesmosis. It is important to focus not only on the fractures but as well on the ligamentous injuries, which are identified by indirect signs on the X-ray.
➢ Type A: fibula fracture below the syndesmosis (Fig. 5.4)
➢ Type B: fibula fracture on the level of the syndesmosis (Fig. 5.5)
➢ Type C: fibula fracture above the syndesmosis (Fig. 5.6).
The Type C-fracture is the most serious type, mostly involving the medial malleolus and the syndesmosis. In some type B- and many type C-fractures a posterior tibial avulsion fragment is seen, the so-called ‘Volkmann triangle’. It is a sign of a lesion of the posterior part of the syndesmosis. Beside the pure fracture lines, the signs of syndesmotic injury are indicating a more complicated ankle injury.

The anterior syndesmosis can rupture as a pure ligamentous injury. Then only indirect signs are present as: widening of the tibiofibular clear space, reduction of the tibiofibular overlap and widening of the medial joint space between talus and medial malleolus. In case of a bony avulsion you can identify a fragment of the tibial tubercle (Tillaux-Chaput fragment).
The malunited ankle fractures will mostly be type B and type C fractures, as these fractures are more severe and often (type B) and regularly (type C) involve the syndesmosis. The malunion reflects the primary dislocation or subluxation or the secondary dislocation due to insufficient immobilization and early weight bearing.</td>
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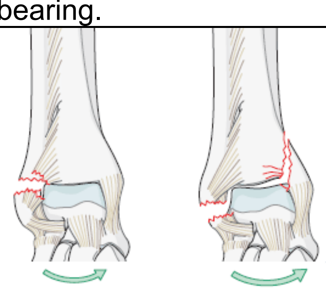
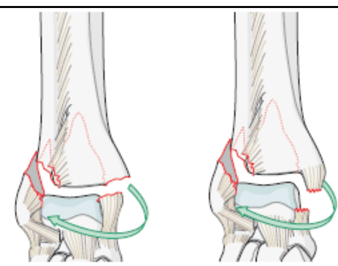
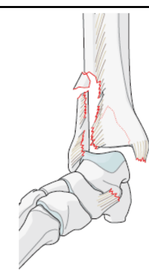
<tr>
<td>Biomechanics of ankle injuries</td>
<td>
Fig 5.4 Type A-fracture without or with medial malleolar fracture. In most Type A-fractures the syndesmosis is intact
© AO Publishing</td>
<td>
Fig. 5.5 Type B-fracture with ruptured syndesmosis and medial malleolar fracture or ruptured medial ligament
© AO Publishing</td>
<td>
Fig. 5.6 Type C-fracture with rupture of the medial ligament (uncommon). In most cases the medial malleolus is fractured. Syndesmotic rupture in most cases. © AO Publishing</td>
</tr>
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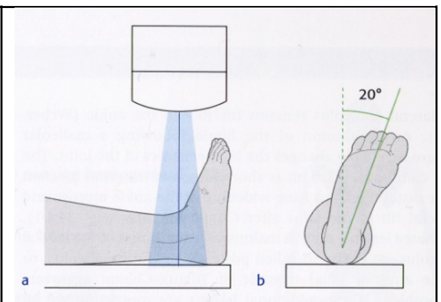
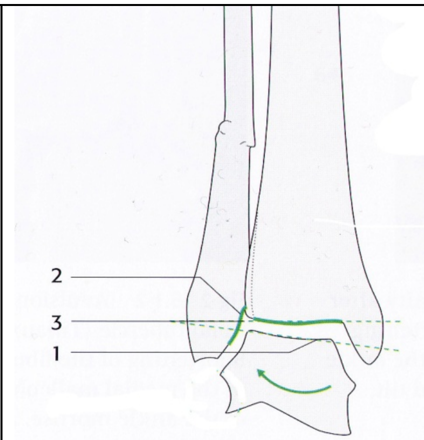
Clinical evaluation	The patient with a malunited ankle fracture presents with: ➢ A history of ankle fracture: Try to find out when and how it occurred. The longer the time elapsed, the more serious are the arthritic changes in the joint. A high energy trauma (fall from a height, sports accident, vehicle accident) is producing more damage to the ankle structures than a low energy trauma (ankle rotation and inversion on an uneven underground). Most of your patients won't have accident x-rays. ➢ An impaired ankle function: What activities are restricted what are still possible? Does the patient rely on crutches? Examine his gait and observe stride and orientation of the foot. The 'heel rise-test' allows evaluating the Tibialis tendon function and shows the eventual hypervalgus of the hindfoot. ➢ A painful swollen ankle: Palpation demonstrates the area of arthritic irritation. Examine and document the range of motion of the injured and the uninjured side. The normal ROM for dorsal extension and plantar flexion is 15°-0°-40°, with the 0° in the middle as an indication that the neutral position is reached. Check for scars, wounds or signs of infection that could affect an operative procedure. Inspect the soles of the feet. The distribution of hyperkeratosis represents the history of weight bearing and the stress to the medial foot in case of hypervalgus.

X-ray evaluation	The radiological evaluation of a malunited ankle fracture consists of: ➢ ap and lateral view of the injured ankle ➢ ap and lateral view of the uninjured ankle Make sure that the correct projection is applied, to obtain the so-called 'mortise view'. For the ap and the lateral view the ankle must be positioned in a 20° internal rotation (Fig. 5.7 b). This allows identification of the above mentioned anatomic landmarks and lines. The uninjured ankle helps to realize individual anatomic ankle form.	 Fig. 5.7 X-ray technique for ‚mortise-view' © AO Publishing

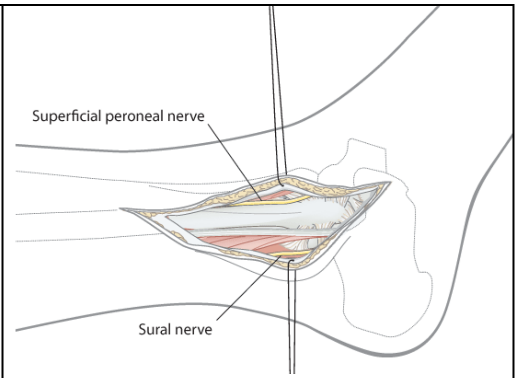
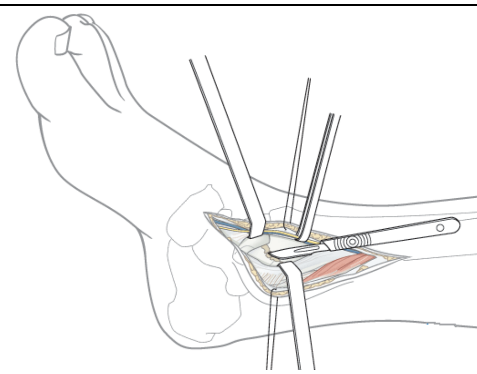
	The patient's x-ray allows to determine the extend of destruction, that occurred to the injured ankle. Make a detailed analysis of the changes to get the maximum of information: ➢ site of malunited fibula in relation to the syndesmosis (allows the classification of the initial fracture) and medial malleolar fracture, ➢ extend of fibula shortening (Fig. 5.8 No. 2) and malalignment of fibula axis (with disruption of the Shenton's line Fig. 5.8 No. 3), ➢ widening of the ankle mortise as sign of the syndesmotic lesion, ➢ changes of the joint line as: medial widening, narrowing in the lateral compartment (arthritis), ➢ malalignment of the joint axis in relation to the tibial axis, as sign of valgus and lateral shift of the talus, ➢ search for bony fragment at the syndesmosis level (Tillaux-Chaput fragment) as sign of an avulsion.	 Fig. 5.8 Radiological changes of a malunited ankle © AO Publishing

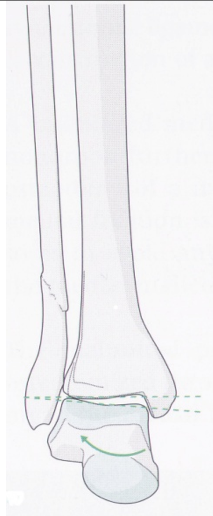
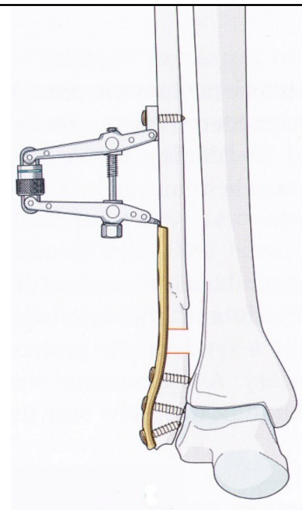
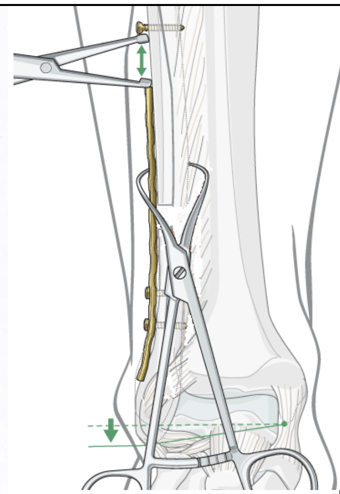
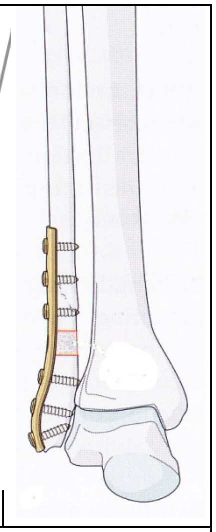
Indications for reconstructive surgery	A secondary reconstruction of a malunited ankle fracture is reasonable for a patient presenting with ➢ the above mentioned radiological signs of malunion, ➢ a preserved ankle function (range of motion) and ➢ arthritic changes of the ankle (joint space narrowing, subchondral sclerosis). The goal of surgery is to restore the ankle anatomy with the reconstruction of the ankle mortise as good as possible. This should slow down the arthritic changes and improve weight bearing and function.

Preoperative planning for reconstructive surgery	 Fig. 5.9	 Fig. 5.10

	Fig. 5.9 This example shows the x-ray of a malunited ankle fracture years after partial removal of the implants. The fibula is shortened and in valgus position. The ankle mortise is widened. The talus has shifted laterally. The medial malleolus is malunited (note the joint line). Medial arthritis is present with narrow joint space. Fig 5.10 The preoperative planning shows restoration of fibula length with a bone transplant, stabilization with a 3.5 mm reconstruction plate. A positioning screw stabilizes the reduction of the fibula in the tibial notch. The surplus of bone at the medial malleolus is to be debrided. The 2 mm axial K-wire that restores the axis of the talus in the tibia is only used intraoperative to maintain reduction. Preoperative planning is an essential step to successful surgery. The clinical and radiological evaluation of the malunited and the healthy ankle defines the extend of deformity to be corrected. In the preoperative planning the necessary steps of correction are identified and sketched in a drawing based on the x-rays: ➢ Lengthening, rotation and varization of the fibula, ➢ size of an eventually necessary tricortical bone transplant from the iliac crest, ➢ reposition of the distal fibula in the incisura fibularis tibiae (tibial notch) ➢ eventual correction of a malunited medial malleolus ➢ restoration of the tibial axis in relation to the tibial axis The planning includes the necessary surgical equipment: ➢ Intraoperative fluoroscopy (C-arm): is essential and allows landmark-guided reconstruction. ➢ plate and screws (3.5 mm reconstruction plate or 3.5 mm 1/3 tubular plate), compression device, small distractor or bone spreader (to distract the fibula fragments after osteotomy), K-wires ➢ Osteotomy set (chisels of different size, curved chisel, hammer), electric drill and saw

Patient preparation and perioperative management	*The day before surgery:* ➢ The leg sows no sign of infection. The soft tissues are not swollen. ➢ The site is marked with a waterproof marker. ➢ The patient is informed about the planned surgery, the risks and the rehabilitation (signed consent form) *Perioperative management:* ➢ Supine position with a pillow under the ipsilateral buttock and a folded blanket under the lower leg ➢ A tourniquet is placed at the leg (350 mmHg up to a maximum of two hours) ➢ Antibiotic prophylaxis: a single dose of 2nd generation cephalosporin. ➢ The lower leg and the anterior iliac crest (bone harvesting) are washed and draped. ➢ Use the WHO checklist for safe surgery.

Surgical approach for reconstructive surgery	*Anterolateral approach to the fibula:* ➢ Scars from primary incisions should be used and modified if necessary. ➢ In a situation without scars a 12-15 cm longitudinal incision is placed over the distal tibia. The superficial extensor fascia is incised (take care of the superficial peroneal nerve), which crosses to the anterior aspect of the foot. ➢ Expose the syndesmotic area by: identification of a syndesmotic avulsion or a bony avulsion (Tillaux-Chaput fragment). ➢ The anterior ankle joint capsule is resected to identify the three cartilage surfaces that should be anatomically reconstructed: distal antero-lateral tibia, distal anterior fibula and lateral talus shoulder	 Fig 5.11 Anterolateral approach to the distal fibula © AO Publishing
	Medial longitudinal incision: ➢ The medial incision follows present scars. ➢ Otherwise it is centred over the medial malleolus and curved distally. ➢ The saphenous vein and nerve should be preserved (use a vessel loop if necessary). ➢ A vertical incision at the anterior margin of the medial malleolus is made to open the joint capsule. This allows inspection of the joint and identification of scar tissue at the medial malleolus or a malunion of the medial malleolus.	 Fig. 5.12 Medial approach to the medial malleolus © AO Publishing

<table>
<tr>
<td rowspan="3">Reconstruction and fixation</td>
<td>   </td>
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<tr>
<td>Fig 5.13 Fig.5.14 Fig. 5.15 Fig. 5.16
Osteotomy and fibula lengthening using a compression device (in the opposite sense) or a bone spreader, bone graft interposition and internal fixation with a 3.5 mm 1/3 tubular plate
© AO Publishing</td>
</tr>
<tr>
<td>Fibula lengthening:

The fibula lengthening should be done at first. The distal fibula is exposed and the anterior capsule resected to identify the landmarks of the cartilage of lateral malleolus, distal tibia and lateral talus.
The osteotomy can be done at the level of the previous fracture (Fig. 5.14). The distal fragment should allow the purchase of at least three screws for the later internal fixation. Use an oscillating saw or a chisel.
The lengthening of the fibula is leading to a correction of the talar shift and tilt (Fig. 5.16). An associated malunion of the medial malleolus or scar tissue at the medial malleolus can prevent the repositioning of the talus. In that situation this medial problems need to be addressed first.
</td>
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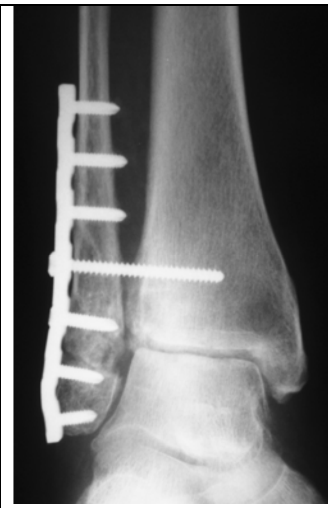
Reconstruction and fixation	*Fibula lengthening (cont.):* ➢ If the soft tissue allows the lengthening can be done by pulling the distal fragment with a bone forceps. Other options are the use of a compression device (Fig. 5.14) or a small bone spreader (Fig. 5.15) used together with a plate fixed to the distal fragment. ➢ The extend of lengthening follows the preoperative planning, the landmarks at the level of the ankle arthrotomy (realignment of the Shenton's line) and the intraoperative fluoroscopy. ➢ In cases with widening of the ankle mortise the distal fibula must be repositioned in to the tibial notch. Eventually the medial malleolus must be addressed to allow the repositioning. ➢ Once the correct length and position of the fibula in the notch is achieved the fibula is fixed to the distal tibia with a 2.0 mm K-wire. ➢ A tricortical bone graft is harvested from the iliac crest in the correct size and pressed into the bone gap of the fibula. ➢ The internal fixation is done with a 3.5 mm 1/3 tubular plate or a 3.5 mm reconstruction plate for heavy individuals. ➢ The Postop x-ray of Fig. 5.17 shows the correction with fibula lengthening, tricortical graft, internal fixation with 3.5 mm reconstruction plate and positioning screw.	 Fig. 5.17 Postop. x-ray of the above mentioned example (see Fig. 5.9 and 5.10)

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<td>
Reconstruction of a malunited medial malleolus:

Nonunion or malunion of the medial malleolus is often associated with a syndesmotic lesion (ligamentous or Tillaux-Chaput avulsion fragment
In the combined lateral and medial malunion the revision of the medial side is the first step to facilitate reduction of the talus.
The medial mal- or nonunion is exposed by a scar adapted or longitudinal or distally curved medial incision.
In case of nonunion the medial malleolar fragment is freed from scar tissue and mobilized. The former fracture surface is freed from sclerotic bone and opened with K-wire drill holes.
In case of malunion an osteotomy is performed at the former fracture site with a chisel.
According to the preoperative planning the medial malleolus is temporarily fixed in its new position with K-wires. The correct position is confirmed by the alignment of the joint surfaces at the antero-medial arthrotomy or by fluoroscopy.
The internal fixation is done by lag screws or tension band wiring.

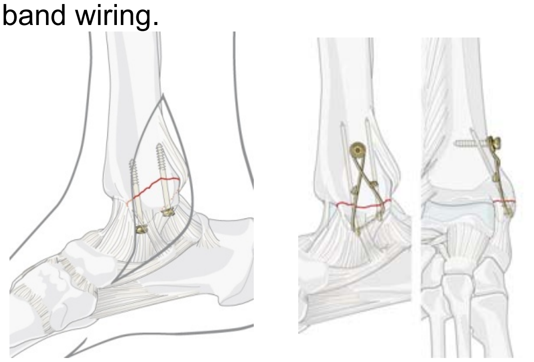
Fig. 5.20 Lag screw fixation and tension band wiring for medial malleolus © AO Publishing
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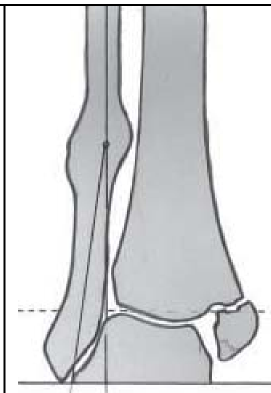
Fig. 5.18 Malunion fibula, nonunion med malleolus
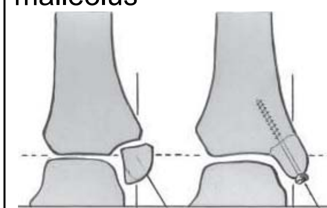
Fig. 5.19 Reconstruction med. malleolus
© Urban & Vogel, Operat Orthop Traumat 2001 No. 4
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<tr>
<td>Rehabilitation and follow-up for reconstructive surgery</td>
<td>
Postoperative care and rehabilitation:

First two weeks until wound healing: removable splint. This allows active and passive exercises to achieve an improved ankle function, without weight bearing. Reduction of swelling by elevation of the operated leg.
Removal of sutures at two weeks.
A below-the-knee non-weight-bearing cast is applied for another 6 weeks. Mobilization with crutches

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Rehabilitation and follow-up for reconstructive surgery	Follow-up: ➢ X-ray of the ankle ap and lateral postoperatively at 8 weeks, 3 months and 1 year ➢ Weight bearing after removal of the cast starting with partial weight bearing and active and passive exercises to regain ankle motion and mobility. Removal of implants: ➢ The removal of the positioning screw should be considered before full weight bearing is allowed. ➢ Some patients feel discomfort at the lateral malleolus because of thin soft tissue coverage. The implants might be removed in the 2nd postoperative year. The consolidation of the reconstruction should be confirmed by clinical and radiological examination.

Indications for ankle arthrodesis	An ankle arthrodesis becomes a treatment option to the secondary reconstruction of a malunited ankle fracture for a patient presenting with: ➢ an impaired ankle function with a reduced range of motion, ➢ a deformity with valgus or varus tilt of the talus and ➢ an advanced osteoarthritis of the ankle (no residual joint space, subchondral sclerosis). The goal of surgery is a bony fusion of the ankle in a functionally favorable position for restitution of a painless weight bearing while avoiding a leg length discrepancy. The contraindications include: ➢ infection of bone or soft tissue ➢ occlusive arterial disease.

<table>
<tr>
<td rowspan="2">Preoperative planning for ankle arthrodesis</td>
<td>The functionally favorable ankle position for arthrodesis is the neutral position in the sagittal plane. The talus must be correctly centered under the tibia in the frontal and sagittal plane. These considerations are the result of biomechanical evaluations and allow normal pressures in the subtalar joint and avoid secondary osteoarthritis in the neighboring joints. The stabilization of the arthrodesis with correctly placed screws gives superior stability compared to other fixation methods (external fixator, intramedullary nail).
The preoperative planning should determine the extend of talus correction:
➢ talus inclination in valgus or varus sense in degree and
➢ anterior or posterior talus translation in mm
In case of considerable inclinations or bony defect a cortical bone graft is necessary.</td>
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Fig. 5.20 Varus tilt of the talus in the frontal plane and anterior translation in the sagittal plane

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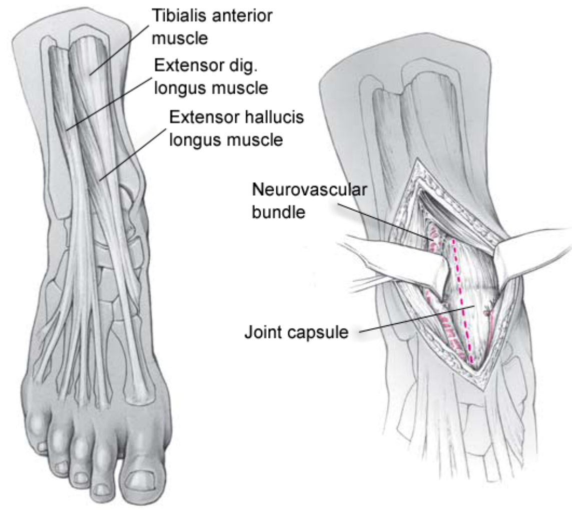
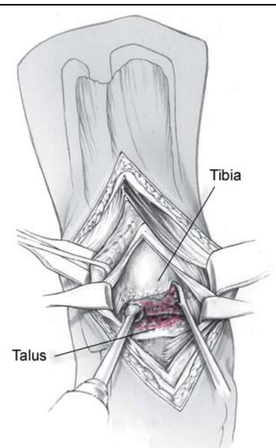
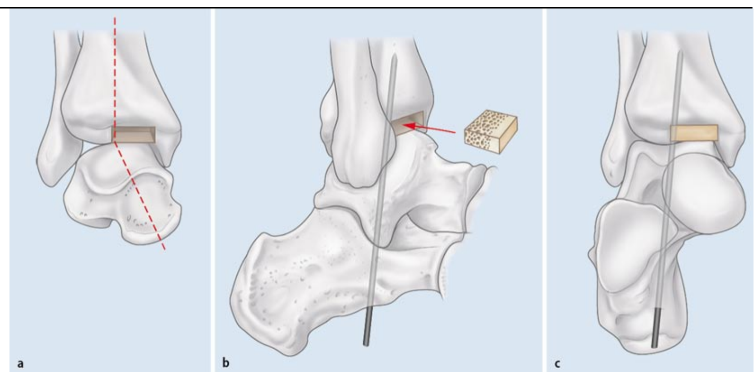
<tr>
<td colspan="2">This is the necessary surgical equipment:
➢ Intraoperative fluoroscopy (C-arm): this operation cannot be done without fluoroscopy, to confirm the correct ankle position, talus reorientation and the position of the screws.
➢ 6.5 mm cancellous bone screws, small distractor or bone spreader (to open the joint space for debridement), 2.5 mm K-wires
➢ Osteotomy set (chisels of different size, curved chisel, hammer), electric drill and saw

For patient preparation and perioperative management see above.</td>
</tr>
</table>

Surgical approach for ankle arthrodesis	The anterior incision (Fig. 5.21) is 10 cm long and centered over the ankle joint. The interval between the Tibialis anterior muscle and the extensor digitorum longus muscle is palpable and serve as landmark. The superficial peroneal nerve should be identified and protected. The extensor retinaculum is incised longitudinally. Between the extensor hallucis longus and the extensor digitorum longus runs the neurovascular bundle (deep peroneal nerve and tibial artery). It is protected with retractors. The joint capsule is resected as well as osteophytes to allow access to the anterior aspect of the ankle joint.	 Fig. 5.21 Anterior approach to the ankle © Urban & Vogel, Oper Orthop Traumatol 2005, No 4/5

Operative technique for ankle arthrodesis	 Fig. 5.22 Ankle debridement © Urban & Vogel, Oper Orthop Traumatol 2005, No 4/5	 Fig. 5.23 Reposition of the talus in the ankle mortise: varus malalignment(a), reposition and bone graft (b) and temporary fixation with K-wire (b and c) © Springer, Trauma Berufskrankh 2010, suppl. 2: 125-131

Debridement of the ankle joint and reorientation of the talus:

- The debridement of remaining cartilage and sclerotic bone on tibia, talus and laterally to the fibula is done with fine chisels, curettes and rongeurs. The bone spreader or distractor is used to improve access to the posterior parts of the joint.
- It is important to carry out the debridement even in the most posterior parts of the joint. The bone surface should bleed slightly.
- If possible the anatomic shape of the ankle should be preserved. In case of incongruence or defect a transplantation of bone graft as corticocancellous bone is necessary. For small defects cancellous bone grafting is sufficient.
- The talus should then be reduced under the tibia (Fig. 5.22) in an exact neutral position of the ankle joint. As an anterior translaton of the talus is often observed, reduction is done by posterior pressure and the use of a folded towel as hypomochlion.
- A 2.5 mm K-wire secures the position of the talus going through calcaneus and talus into the distal tibia (Fig. 5.22). The maintenance of this position is of utmost importance. It is checked by fluoroscopy and eventually corrected.

Operative technique for ankle arthrodesis

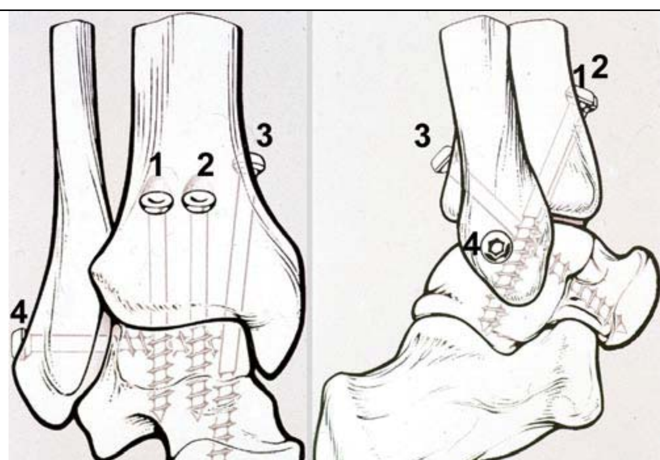
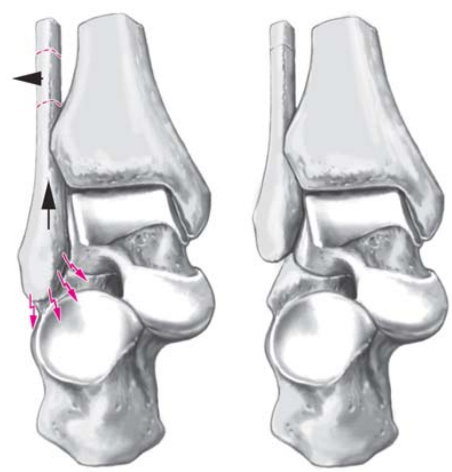


Fig. 5.24 Order of placement of the four 6.5 mm cancellous lag screws
© Springer, Trauma Berufskrankh 2010, suppl. 2: 125-131

Fig. 5.25 Insertion of screw No 3 from behind the medial malleolus
© Springer, Trauma Berufskrankh 2010, suppl. 2: 125-131

	Internal fixation by screw arthrodesis: ➢ A stable internal fixation is achieved with four 6.5 mm self-cutting cancellous lag screws (Fig. 5.24). The internal fixation is started with the two parallel anteriorly inserted screws. The insertion starts with drill holes 4 cm proximal to the joint space, angulated at 20° to the tibial axis, aiming at the medial and lateral part of the talar dome. ➢ With this screws in place and controlled by fluoroscopy, the K-wire can be removed. ➢ A third screw is inserted through a posteromedial stab incision approximately 3 cm proximal to tip of the medial malleolus (Fig. 5.25). It is advanced into the talar neck and into the antero-lateral portion of the talar head. ➢ The forth screw is inserted over a tab incision at the level of the tip of the lateral malleolus. It engages in the distal fibula end the talar body. The fluoroscopy is important as the space in the talar body is limited by the screws no 1-3. ➢ At the end of surgery the fluoroscopy should document the correct position of the ankle and the placed screws. Special attention should be paid to the talo-navicular and the subtalar joint. ➢ After the release of tourniquet a meticulous hemostasis is important. As the cancellous surfaces tend o bleeding a suction drain should be inserted. ➢ The extensor retinaculum and the subcutaneous tissue are sutured with 3-0 resorbable threads in interrupted stitches. Skin closure with interrupted non resorbable 3-0 suture material. ➢ Split below-knee cast

Errors and complications with ankle arthrodesis	➢ Incision too lateral: danger of injury to the neurovascular bundle. ➢ Insufficient screw purchase: use washers, eventually more proximal insertion of the anterior screws. ➢ Uneven resection or omitted bone-graft: insufficient centering of the talus into the ankle mortise, no consolidation. ➢ Too generous resection of the articular surfaces resulting in over length of the fibula (Fig. 4.26): impingement syndrome, treated by shortening osteotomy of the fibula.	 Fig. 5.26 Excessive length of the fibula can cause impingement, treated by shortening osteotomy © Urban & Vogel, Oper Orthop Traumatol 2005, No 4/5

Rehabilitation and follow-up for ankle arthrodesis	Post-op care and rehabilitation: ➢ Elevation of the operated limb in the split below-knee cast. ➢ Beginning at the 2nd postoperative day the cast is removed for functional treatment of the subtalar and Chopart joint and replaced after the exercises. ➢ The patient is allowed out of bed using forearm crutches for non-weight bearing. ➢ After wound healing a closed below-knee cast is applied and 15 kg partial-weight bearing is allowed for 6 weeks (no bone-grafting) and 12 weeks (extensive bone-grafting) Follow-up: ➢ X-ray of the ankle ap and lateral postoperatively at 6 weeks, 3 months and 1 year ➢ Weight bearing after removal of the cast starting with partial weight bearing and active and passive exercises to regain motion of the subtalar and Chopart joints. Removal of implants: ➢ Some patients feel discomfort at the lateral and malleolus because of thin soft tissue coverage. Partial implant removal can be considered after clinical and radiological consolidation, but not before 1 year.

Further reading	1. René K Marti, Ronald J van Heerwarden, Osteotomies for Posttraumatic Deformities, AO Publishing 2008, Thieme New York, ISBN 978-3-13148671-4 2. Daniel Weber, Daniel Fritschy, Nikolaus F. Friederich, Werner Müller, Osteotomy of the Distal Fibula for Correction of Posttraumatic Malunion, URBAN & VOGEL Operat Orthop Traumatol 2001; 9: 273-83 3. Thomas Enders, René Grass, Stefan Rammelt, Hans Zwipp, Ankle Arthrodesis with Four Cancellous Lag Screws, URBAN Vogel, Operat Orthop Traumatol 2005; 17: 345-60 4. Hans Zwipp, Arthrodesis versus Arthroplasty, Springer Trauma Berufskrankh 2010, 12 (Suppl. 2): 125-131 5. Thit Lwin, Tibio-Talo-Calcaneal Fusion Using SIGN IM Nail, Lippincott Williams & Wilkins, Techniques in Orthopaedics, Vol 24, No. 4, 2009

Acute Osteomyelitis

Carl Albertson, MD

Introduction:

Osteomyelitis is an inflammation of bone caused by a pyogenic organism. Historically, osteomyelitis has been categorized as acute, subacute or chronic, with the presentation of each type based on the time of disease onset (i.e., occurrence of infection or injury). Acute osteomyelitis develops within two weeks after disease onset, subacute osteomyelitis within one to several months and chronic osteomyelitis after a few months. In this chapter we will focus on acute osteomyelitis.

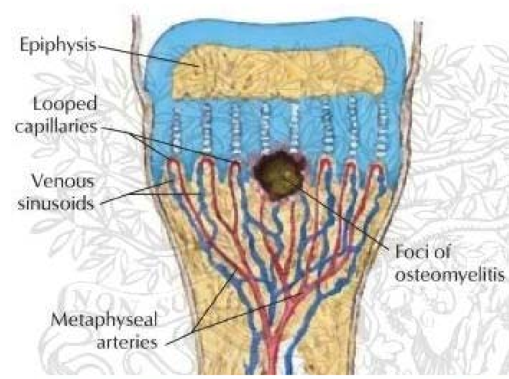
Acute osteomyelitis is more commonly seen in children than adults. The infection is usually blood born and affects the metaphyseal areas of long bone, especially in the lower extremities. In adults the vertebrae are the most commonly affected bone.

Early diagnosis and treatment is critical if the complications of chronic osteomyelitis are to be avoided.

Pathophysiology:

In general, microorganisms may infect bone through one or more of three basic methods: via the bloodstream, contiguously from local areas of infection (as in cellulitis or myositis), or penetrating trauma.

Acute osteomyelitis is most commonly found in children. It is usually hematogenous in origin. The infection began with the lodging of bacteria in the post capillary sinusoids on the metaphyseal side of the epiphyseal plate. Here as the arterial flow transitions to venous outflow there are sinusoids and vascular loops which contributes to a sluggish movement of the blood and it is often here that the bacteria begin the infection. Once the bone is infected, leukocytes enter the infected area, and in their attempt to engulf the infecting organisms they released enzymes that further lyse the bone. This is considered the acute phase.



If left untreated, an abscess cavity forms within the bone. By 72 hours, inflammatory processes are well developed. As the abscess cavity enlarges, pressure is produced within the metaphysis and eventually the infection spreads to the cortex. Thrombosis of the venous sinus and nutrient artery can occur with bacterial proliferation and result in a loss of medullary blood supply, slowing mobilization of infection-fighting cells. It can then erode through the cortex and spread down to bone under the thickened periosteum eventually devitalizing the cortex. In this chronic stage the devitalized cortex can become a **sequestrum** while the elevated periosteum is still able to lay down new bone which becomes the **involucrum** of chronic osteomyelitis.

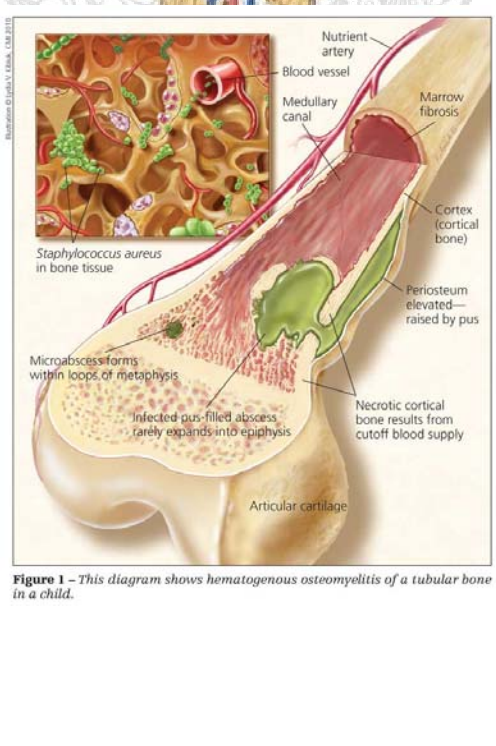
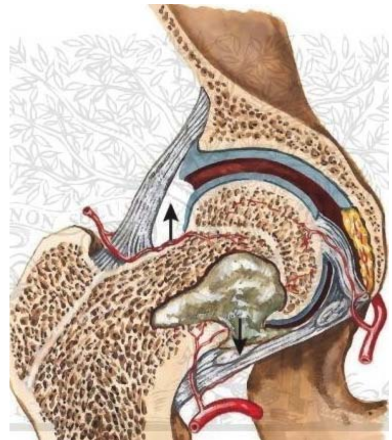


Figure 1 – *This diagram shows hematogenous osteomyelitis of a tubular bone in a child.*

In children, acute osteomyelitis rarely involves the epiphysis as the epiphyseal plate acts as a barrier to the metaphyseal infection. However, infants may still get septic arthritis from a metaphyseal infection as part of the metaphysis can be intra-articular as is seen in the picture of a hip infection. If the infection erodes through the cortex, it can become intra-articular and cause septic arthritis. This usually happens in children less than 12 months of age. Septic joints have been shown to occur adjacent to infected bone and most commonly occurs at the knee but are also possible in the hip, ankle, and shoulder.



Most commonly, and because of the particulars of their blood supply the tibia, femur, humerus, vertebrae, maxilla and mandible bones are more commonly affected in children while, acute osteomyelitis is more common in vertebra for adults.

Most common organisms by age group

Newborns (younger than 4 mo)
S. aureus, *Enterobacter* species, and group A and B *Streptococcus* species
Children (aged 4 mo to 4 y)
S. aureus, group A *Streptococcus* species, *Haemophilus influenzae*, and *Enterobacter* species
Children, adolescents (aged 4 y to adult)
S. aureus (80%), group A *Streptococcus* species, *H. influenzae*, and *Enterobacter* species
Adult
S. aureus and occasionally *Enterobacter* or *Streptococcus* species

Evaluation and diagnosis

The diagnosis of acute hematogenous osteomyelitis in children is difficult, and the diagnosis is still often delayed. The most important factors in making the diagnosis are the clinical findings, and a high index of suspicion is essential on the part of the clinician. Unexplained bone pain with fever indicates osteomyelitis until proven otherwise. Patients with acute osteomyelitis often have pain, fever, malaise, local swelling and may have limited use of the limb. There may be a history of blunt trauma, sore throat or other intercurrent infection.

Tenderness is greatest in the metaphyseal region of the involved bone. Movement of neighboring joints is limited, but sometimes early on painless motion is possible.

Leukocytosis and elevations in the erythrocyte sedimentation rate and C-reactive protein level may be noted. Blood cultures are positive in up to one half of children with acute osteomyelitis. Aspiration of the bone, abscess, or joint is essential for diagnosis and cultures.

Radiographs of the bone are usually normal during this phase but may show soft tissue swelling as evidenced by a loss of the soft tissue planes. As the infection progresses in the medullary canal, lytic areas may be evidenced on radiographic examination. Later, there may be periosteal new bone formation and possible sclerosis if an involucrum is occurring.

Aspiration is critical for bacteriologic diagnosis and should be done early, even if there is no abscess. The technique involves locating the point of maximum tenderness and swelling (usually in the metaphysis) and then using a 16- or 18- gauge spinal trocar needle to aspirate material extraperiosteally, subperiosteally, and intraosseously. All material should be smeared and cultured, and antibiotics should be started on the basis of the most likely suspected organism while awaiting definitive culture results. Aspiration produces positive results in 60% of patients and biopsy in 90%.[1]

Ultrasonography and computed tomographic (CT) scanning may be helpful in the evaluation of suspected osteomyelitis. An ultrasound examination can detect fluid collections (e.g., an abscess) and surface abnormalities of bone (e.g., periostitis), whereas the CT scan can reveal small areas of osteolysis in cortical bone, small foci of gas and minute foreign bodies.

Rarely, epiphyseal separation can occur as a result of hematogenous osteomyelitis. If this rare condition does occur then the epiphysis must be internally fixed in its anatomic position as well as the infection treated both surgically and medically.

Treatment

After blood tests, blood cultures, and aspiration, begin parenteral antibiotics for Gram positive organisms, such as cefazolin 100 mg/kg/day. Once the fever has abated and there is minimal to no discomfort on palpation of the extremity and if possible the CRP has returned to normal the patient can then be switched to oral antibiotics which in recent studies have shown to be quite effective for osteomyelitis. The oral antibiotics should be continued for 6 weeks however.

General supportive measures should include intravenous fluids and analgesia medications. The painful limb often requires a splint or skin traction to relieve symptoms.

Most children older than 1 year and with a duration of symptoms of less than 48 hours respond to antibiotic treatment alone (without surgery). If a child does not respond to antibiotics within 36 hours, surgical debridement should be considered. The primary role of surgery is to evacuate purulent material. If the pus accumulates under the periosteum for any length of time, the periosteum can be destroyed. The periosteum may serve as the only source of osteogenic regeneration of the dead bone so try to save it. If the bone does not regenerate, a permanent defect may result. An appropriate aphorism is “Antibiotics save the life; surgery saves the bone.”

Technique for draining the abscess

1 Using anaesthesia, perform a surgical preparation of the affected region. Make an incision directly over the metaphyseal region of the affected bone in the area of the most swelling.

2 Carry the incision through the skin, subcutaneous tissue, muscle and periosteum. If pus is not evident, make multiple drill holes through the cortex of the bone into the medullary canal to allow the trapped pus to escape.

3 Irrigate the cavity to remove all purulent material. Close the skin loosely over a drain and send a sample of the infected material for bacteriological examination.

4 For infections after the acute phase, treatment is aimed at drainage of the abscess cavity while allowing involucrum formation to proceed.

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1 AAOS Instructional Course Lectures, Volume 54, 2005 pp.517

5 Delay removal of the sequestrum until the involucrum has matured, a process which takes between 6 and 12 months. Antibiotic use at this stage should be limited to treatment of active soft tissue infection, systemic illness, locally aggressive infection, or before and after surgical sequestrectomy.
6 When the involucrum has formed adequately, the sequestrum can be removed to control the residual infection. Sequestrectomy may be difficult if the sequestrum is large, and care should be taken to avoid fracture of the remaining involucrum. The sequestrum may become trapped within the involucrum and might need to be fragmented for removal. After surgery, protect the limb with a cast to prevent a fracture. Close the wound over drains or leave it open for later split thickness skin grafts.
7 Patients with an acute flare of a chronic osteomyelitis are common. It is not unusual for the infection to have been silent for many years, then to flare, accompanied by an acute soft tissue infection, with or without a draining sinus. Usually a sequestrum can be found as the source of the residual infection. Treat with antibiotics, drainage of the soft tissue abscess and removal of the sequestrum.
8 If the involucrum has not formed or is insufficient to maintain a functional extremity, reconstructive procedures are usually necessary once the infection is controlled. These are elective procedures which may not be appropriate in the district hospital.

Other presentations of acute osteomyelitis

Vertebral osteomyelitis:
Acute osteomyelitis in the adult usually affects the vertebra. These patients present with pain in the spine at the location of the infection. There may be considerable pain when the spine is moved. They usually have an elevated temperature and may have an elevated white blood count. Blood cultures should be obtained and antibiotics started. It is usually not possible to get a culture directly from the infection. Immobilization can be helpful for pain control

Sickle Cell Anemia Patients
In a study from Nigeria[2]
Age range was 2 to 45 years with a median of 23 years. *Klebsiella* species were cultured in 45% of the blood samples. *Staphylococcus aureus* was responsible in 20%, *Salmonella* species in 8% and *Streptococcus pyogenes* was cultured in 4% of the samples. From direct wound swab culture, *Klebsiella* was responsible for 36%, *Staphylococcus aureus* 28% and coagulase-negative *Staphylococcus* 24%. *Proteus* species were responsible for 8% and *Salmonella* was cultured in 4%. The highest number of patients presenting with osteomyelitis occurred in the second decade. From (culture) sensitivity tests, ceftazidine and Ofloxacine were found to be the most effective antibacterial drugs.

Neonatal osteomyelitis[3]
Neonatal osteomyelitis differs from acute hematogenous osteomyelitis in four ways: (1) the musculoskeletal anatomy of the neonate is unique, and an infection ultimately affects growth of the physis and/or enters the joint in 76% of patients; (2) the organism that causes the infection may differ from that seen with acute hematogenous osteomyelitis; (3) multiple sites are

2 West Afr J Med. 1995 Oct-Dec;14(4):255-8.

3 AAOS Instructional Course Lectures, Volume 54, 2005 pp.518

commonly involved (40% of patients); and (4) infants have an immature immune system, and therefore diagnosis can be difficult.

Neonates and young infants with osteomyelitis have a unique anatomy that differs from that of older children with acute hematogenous osteomyelitis. For example, before the epiphyseal ossification centers form in the proximal part of the femur, metaphyseal vessels penetrate directly into the cartilaginous precursor. Infection can destroy these fragile growth centers and enter the hip joint directly. Transphyseal vessels persist for up to 12 to 18 months. In older children, the physis serves as a mechanical barrier to infection, but in infants, the osseous architecture is more fragile and is very easily injured. The morbidity rate is higher (up to 76%) for neonates.

Neonates with osteomyelitis have an immature immune system, are less able to produce an inflammatory response, and are susceptible to organisms that are less virulent in older children and adults. The temperature and white blood cell count of neonates with osteomyelitis may be normal, and there may be few findings on physical examination or imaging (including false-negative results on bone scans). Often, these factors delay the diagnosis.

Chronic Osteomyelitis

Robert F. Greene, MD

Chronic osteomyelitis can have many causes. Most often it arises from the hematogenous route, but it can be caused by open fractures or from contiguous infections. The treatment approach varies according to the situation:

Chronic osteomyelitis (COM) resulting from Acute Hematogenous Osteomyelitis

This is a common syndrome in Africa. It begins exclusively in children and occurs very often in Sickle Cell Disease

Management is different in the 2 major forms of this kind of COM: with or without pathologic fractures.

COM in patients without pathologic fractures

This is the easiest to treat. I compare it to pulling a tooth. The bone is stable, so the sequestrum is simply extracted. It may be necessary to make a bone window in order to have room for it to come out. A sequestrum is movable, has no periosteum, has a metallic click when touched with an instrument and is whitish or gray. Healthy living bone is reddish and bleeds easily. Do not remove this with the curetting. Often there are small slivers or fragments. It is generally advisable to leave the wound open, so that missed pieces can find their way out, and to let it close by itself in a few weeks. The family changes the dressings at home. It's just like a dental patient with a tooth extraction.

Sickle Cell Osteomyelitis
Be cautious about operating early in Sickle Cell patients, since apparent sequestra may often be slowly reincorporated. The bone may recover in sterile ischemic episodes. In chronic SC osteomyelitis Salmonella is frequently the infecting organism. It is the most difficult to treat due to failures and relapses. Often multiple sites are infected. Procedures are limited due to anemia and restrictions on transfusions.



IT'S LIKE PULLING AN INFECTED TOOTH!

COM in patients with pathologic fractures

When pathologic fractures occur in COM, the surgical removal of large sequestra in unstable bones of the upper and lower extremities should be delayed until the involucrum has formed and the limb is stable. In order to achieve this, the limb is usually casted to avoid angulation, shortening and pain. Dressings are changed via windows in the cast. Oral antibiotics are used only for flare-ups of infection signaled by increased pain, fever, soft tissue swelling and increased out-pouring of pus. The sequestrum serves as a spacer, holding length, and also as a mold, forcing the involucrum to create a cylindrical new bone. It seems contrary to normal surgical principles to leave a dead piece of bone in the body, but in this case, while it is still serving a function, it makes sense to delay the removal of the sequestrum. The timing of the sequestrectomy depends upon the formation of a bridging involucrum which heals and stabilizes the bone.

If a sequestrum falls out, continue with immobilization and dressing changes. Bone graft or fibula transfer may be needed to stabilize the bone.

When the involucrum has formed, it is time to do the sequestrectomy. Use multiple smaller incisions rather than a long incision the length of the leg. Long incisions like this will never close. Make the smallest bone windows possible to give access to the infected cavity. Break the sequestrum up rather than enlarge the window. Gentle curettage and wiping with gauze is followed by repeated irrigation. Prior Methylene Blue staining helps the surgeon know when to stop. Gauze packing completes the procedure, followed in most cases with further immobilization if the involucrum is weak.

Avoid the mistake of radically curetting away every bit of bone available. The bone is not bad just because it is soft. This misguided activity just creates new pathologic fractures. The family now can change the dressings at home and use occasional oral antibiotics only if needed. This is an amazingly cost-effective way of managing this very common disease.

Steps in Sequestrectomy

- Get xray to see the size & shape of the sequestrum
- Use a tourniquet to limit blood loss and make necrotic material more visible
- Inject Methylene Blue in the sinus to stain infected material
- Use 2 or 3 smaller incisions, not a long one.
- Break the sequestrum in pieces
- Curette gently, leave living bone
- Do not "unroof," use smaller windows
- Pick the thinnest bony area to make a window
- Outline the window with drill holes, then join holes with an osteotome
- Oval windows are better
- Minimize periosteal stripping
- Protect nerves and vessels
- Wipe with gauze and irrigate cavities and channels
- Leave the wound open, at least partially, to allow debris to exit
- Immobilize if the involucrum is weak or incomplete
- Careful with blood loss, especially in the femur and humerus
- 5-7 days of oral antibiotics
- Pus on early dressing changes means failure. Repeat the xray and debridement.

Chronic Osteomyelitis from other sources

The initial management almost always requires debridement under anesthesia in the operating room to remove necrotic and infected material including sequestra and hardware. Cultures and smears at this time help direct the choice of antibiotics. The fracture may be reduced and stabilized with splinting or external fixation, when the infection is controlled. Sometimes traction may be used. Occasionally an oblique Steinmann Pin can be used temporarily to hold reduced bone ends together until a cast is placed. Do not use plates, screws and IM nails in infected bones. As soon as possible bone, tendons, nerves and vessels are covered with muscle flaps and skin grafts. Wound vacs or daily dressings are used.

External fixation should only be used, in most cases, for 6-8 weeks before some method of "dynamization" is used. This is usually the length of time it takes for some new bone to be seen on xray. For example the rigidity of the external fixator could be decreased by reducing the number of pins or fixation bars, or by loosening the set screws on sliding devices. This is called dynamization. Also the limb could be placed in a cast after removal of the external fixation pins. These steps have the effect of allowing the fracture fragments to be compressed together more and are thought to promote more rapid union.

Some find that Gentamycin polymethyl-methacrylate (PMMA) beads help to fill dead spaces where bone is missing. If beads are not readily available, success can also be achieved with daily dressing, taking care not to over-pack the wounds.

Assess progress of bony union with xrays and occasionally manually. If there is delay in healing of the bone, proceed with bone grafts early on. Cancellous iliac crest bone chips may be placed deep in a clean open wound ("Papineau technique") or the chips can be placed next to the fracture site. Generally it is preferable to wait for complete skin healing before the grafting. To fill in gaps in long bones some form of the Ilizarov technique may be employed ("bone transport").

If internal fixation is planned in previously contaminated, but now quiescent, fractures, intramedullary nails are generally much preferred to plates and screws.

Whenever the fracture becomes "sticky" it is often helpful to use a "cast-brace" which involves placing hinges between the casts on arms and legs for elbows, knees and/or ankles, allowing movement of these joints. This is beneficial because if helps restore joint movement, helps build muscle and also accelerates fracture healing. Hinge made from plastic hose

Cast-brace

Septic Arthritis

Tim Oswald, MD
Anil Thomas, MD

Septic arthritis is an infection and inflammation of the synovial membrane of any joint capsule with purulence into the articular space. If left untreated, its disastrous consequences include permanent joint damage, osteomyelitis of neighboring bone, sepsis, and even death. The key to preventing these complications is early detection and prompt management.

The overall incidence of septic arthritis is about 2-10 cases per 100,000 in the general population. It is higher in those with systemic inflammatory conditions such as rheumatoid arthritis and systemic lupus erythematosus, and those with immunologic disorders. Septic arthritis can arise from both hematogenous spread and from direct inoculation from a foreign body into a joint. Bacterial etiology of septic arthritis also varies in different age populations. In the age group older than six months, 60% of cases are due to *Staphylococcus aureus*, 15% beta-hemolytic *Streptococcus* (*S. pyogenes*, *S. agalactaie*), 5% *Streptococcus pneumonae,* and 20% Gram-negative organisms. In the age group less than 6 months old, *S. aureus* and Gram-negative organisms predominate, including *Haemophilus influenzae* (where vaccination against this organism is not available). In the sexually active population, *Neisseriae gonorrhea* can also be a cause of septic arthritis. This is important into determining the appropriate antibiotic regimen.

Septic arthritis usually presents with fever and a warm, swollen joint. There may be associated erythema surrounding the joint. In addition, the joint is exquisitely painful on range of motion maneuvers. Patients typically are unable to bear weight on the affected extremity due to significant pain. The next step in the evaluation of septic arthritis is arthrocentesis of the affected joint and fluid analysis of the aspirate. The sample usually appears extremely cloudy or opaque with pus often times obtained from the joint. White blood cell (WBC) count in the synovial fluid is typically greater than 75,000-100,000 cells per microliter (mL). Gram stain under microscope may or may not show bacteria. Culturing the sample usually yields a bacterial pathogen. However, one can not wait the days for culture results to return in order to act on treating septic arthritis. Serum WBC is usually also elevated along with serum erythrocyte sedimentation rate (ESR) and C-reactive protein (CRP). If the facilities for fluid and serum analysis are not available, the clinical symptoms as discussed may alone be necessary in the diagnosis of septic arthritis.

The standard treatment of septic arthritis includes aspiration of the joint for fluid analysis and cultures prior to antibiotics, followed by surgical debridement and intravenous antibiotic therapy. The following sections discuss the anatomic landmarks and surgical approaches for joint aspiration and irrigation and debridement (I&D), respectively, of commonly affected regions.

The Knee

The knee is one of the easier joints to aspirate and approach for I&D, and is also the most common joint in adults to be affected by septic arthritis. Symptoms are warm, erythematous, swollen knee with significant pain on range of motion and inability to bear weight. Aspiration of the knee can be accomplished through a superolateral approach with the needle inserted at the superolateral border of the patella and directed in an inferomedial direction deep to the patella. Irrigation and debridement of the knee is usually done through a median parapatellar approach. Once the knee is sterilely prepped, a small (4-5cm) skin incision is made on medial border of the patella and carried down the retinaculum. A similar medial border incision is made in the retinaculum and access into the knee joint is obtained. The knee can be thoroughly irrigated through this approach and can be closed with a drain.

The Hip

The hip is the most commonly affected joint in children. Patients usually present with pain on range of motion and inability to bear weight. At time, pain can also be referred to the knee of the affected extremity. Ultrasound (if available), may demonstrate effusion within the hip. Aspiration can be accomplished through the anterior and lateral approaches. In the anterior approach, the entry point is 2cm lateral to the femoral artery and 2cm inferior to inguinal ligament, and the needle is advanced medially and posteriorly towards the femoral neck and hip joint. In the lateral approach, the needle is inserted at the level of the superior tip of the greater trochanter and just anterior to it. The needle is advanced medially, 45 degrees cephalad and parallel to the table. In both approaches, contrast dye can be injected into the joint under fluoroscopy to confirm intraarticular placement.

Irrigation and debridement of the joint is accomplished through the anterior approach to the hip. The interval is between the **sartorius** and **tensor fascia latae (TFL)** muscles. Be aware of the lateral femoral cutaneous nerve that lies superficial to the sartorius and TFL. Once the sartorius is retracted medial and TFL laterally, there may be the ascending branch of the lateral femoral circumflex that may have to be ligated and divided. Deep to that is the **gluteus medius** and **rectus femoris.** Detach rectus femoris from it origin on anterior acetabulum and anterior inferior iliac spine and reflect inferiorly, exposing the capsule. Incise capsule and proceed with debridement. Closure may be done over a drain.

The Ankle

The ankle can be aspirated by inserting a needle just medial to the tibialis anterior tendon at the level of the ankle joint and advancing in a direction perpendicular to the floor. For irrigation and debridement, the anterior approach the ankle is used. A longitudinal incision is made over the midline on the anterior aspect of the ankle. Under the skin is the superficial peroneal nerve and should be retracted laterally. Incise the extensor retinaculum between the extensor hallucis and extensor digitorum longus tendons. Approach the ankle between these two tendons and retract the deep peroneal and tibial anterior arteries away. Make a longitudinal incision in ankle capsule to access the joint and proceed with irrigation and debridement.

The Shoulder

The glenohumeral joint can be aspirated from a posterior approach. The needle is inserted 2cm inferior and medial to the tip of the acromion and advanced towards the coracoid process. Irrigation and debridement can be accomplished the arthroscopic technique using standard anterior and posterior portals. Open irrigation and debridement is achieved using the deltopectoral approach. Patient is placed supine in beach chair position. Incision is made in the deltopectoral groove. Avoid cephalic vein that is in field of dissection. Access the glehumeral joint by incision the capsule through the rotator interval, which is the triangular section of capsule formed by the supraspinatus and subscapularis muscles. Again, the joint can be closed over a drain and with monofilament absorbable suture.

The Elbow

The elbow joint may be accessed for aspiration from a lateral approach. A triangle region is imagined with the its corners being the lateral epicondyle, radial head, and tip of the olecranon. These bony landmarks are easily palpated and the soft tissue region within this triangle is the entry point for aspiration. The needle is directed and advanced medially to access the elbow joint. Irrigation and debridement can be done through the lateral approach. An incision is made laterally over the lateral epicondyle. The triceps muscle is separated from the extensor carpi radial longus anteriorly and the capsule is exposed and subsequently incised for irrigation and debridement. The wound can then be closed over a drain.

The Wrist

Along with the elbow, the wrist is an uncommon site for septic arthritis. About 5-10% of the septic arthritis cases involve the elbow and/or wrist. Aspiration can be accomplished by first palpating Lister's tubercle on the dorsum of the wrist and inserting a needle slightly distal and ulnar to the extensor pollicis longus (EPL) tendon and into the wrist joint. Irrigation and debridement is typically done through the dorsal approach. An longitudinal incision is made between the EPL and extensor digitor communis (EDC) tendons. Next the extensor retinaculum is incised between the EPL and extensor indicis propis (EIP), to expose the wrist capsule. The capsule is then incised for irrigation and debridement.

Antibiotic Therapy

In general, most cases septic arthritis requires 4 weeks for antibiotic therapy. Cultures of specimens taken should also undergo antibiotic sensitivity testing for selecting the most appropriate medication. Treatment of methicillin (or oxacillin) sensitive *S. aureus* is usually with 4 weeks of intravenous (IV) antibiotic therapy. Similarly, methicillin (or oxacillin) resistant *S. aureus* requires 4 week of IV antibiotics. *H. influenza* can be treated with 2 weeks of IV antibiotics and Pseudomonal infections are treated for 3-4 weeks. Those with gonoccocal septic arthritis can be treated with IV ceftriaxone for 1 week and then oral antibiotics such as ciprofloxacin 500mg twice daily. In situations of concominant osteomyelitis, antibiotic therapy may have to be extended to a total treatment period of 6 weeks.

Septic arthritis is a very serious and destructive orthopaedic process. Its sequelae range from permanent joint destruction to even systemic sepsis. Early diagnosis and treatment with debridement and antibiotic therapy are crucial in preventing these complications.

Fractures of the Femur in Children

John Tanksley, MD

HIP FRACTURES

Hip fractures in children typically are caused by high energy mechanisms, but pathologic fractures do occur. Due to the complex boney and vascular anatomy, complications like malunion and avascular necrosis of the femoral head are common. Undisplaced fractures which are treated initially in a spica cast are prone to displace over time and heal with a varus malunion. This in turn causes the hip abductor muscles to shorten and lose power which in turn causes a gait deformity. For this reason, the **conservative treatment of children's hip fractures is operative treatment**.

Diagnosis

A fracture of the hip is suspected from a history of trauma followed by the inability to bear weight. Hip fractures are frequently missed in patients with a fractured femur because the surgeon fails to follow the rule to x-ray the joint above and the joint below the fracture. In the casualty department, a careful exam of an alert patient will reveal pain and guarding on gentle internal and external rotation of the patient's hip. In the multiply injured or comatose patient remember to take a screening AP radiograph of the pelvis as a part of your trauma work up in order to screen for fractures and dislocations of the pelvis and hips. Since some fractures of the hip may not be detected on the AP x-ray, a lateral hip x-ray is helpful to help make the diagnosis and to assess for fracture displacement.

Treatment

Displaced hip fractures

Under the ideal conditions of having a skilled surgeon and C-arm fluoroscopy, these fractures are best treated with closed or open anatomical reduction and internal fixation, followed by a hip spica cast for six weeks. If you do not have the experience or equipment to perform open reduction and internal fixation of hip fractures on adults at your hospital then referral to an orthopedic surgeon is recommended. However if your orthopedic consultant does not have x-ray control in the operating theatre, then your patient may be better off getting treated in skeletal traction in your own hospital. The author's opinion is that treatment initially in traction followed by a spica cast is more likely to lead to an acceptable outcome than would occur with referral to a colleague who treats the patient in an immediate spica cast or with surgery done without proper intraoperative x-ray control.

Surgical Treatment: After the fracture is reduced, the anatomical level of the fracture dictates slight variations in the internal fixation technique:

- Fractures through the proximal epiphysis: Place 2 or 3 smooth pins across the epiphysis but avoid penetration into the joint.
- Femoral neck fractures: Use 2 or 3 smooth pins across the fracture (which may cross the epiphysis if necessary), or 2 small screws which stop short of the epiphysis.
- Base of femoral neck fractures: Fix with screws or pins which stop short of the epiphysis.
- Intertrochanteric fractures: Fix with screws or pins which stop short of the epiphysis.

Fixation is seldom rigid, so protect the patient for the first 6 weeks in a hip spica followed by crutches until x-rays show the fracture is healed. Apply the spica with the hip and knee in enough flexion so that the patient will be unable to bear weight on the leg. The fracture heals over seven to ten weeks depending on the patient's age. The non-union rate is 5-10%. Pins that cross the growth plate are removed after the fracture heals fully.

Traction:

Place the patient in skeletal traction with an initial traction weight equal to 15% of the patient's body weight. It is helpful to obtain portable biplanar radiographs weekly to determine the status of fracture reduction. The amount of traction may need to be increased or decreased to correct fracture angulation. Depending on the patient's age, after four to five weeks in traction the fracture will become “sticky” (deformable without being displaceable). At this time the patient is placed in a spica cast for another four to five weeks.

Nondisplaced hip fractures

Nondisplaced hip fractures in children are uncommon. Internal fixation should be performed early to prevent the fracture from displacing. A hip spica cast followed by protected weight bearing follows. Traction followed by spica casting is an alternative treatment, as has already been discussed.

Hip Dislocations

In children under 10, low impact trauma like a fall may cause a hip dislocation. Dislocations in adolescents usually are caused by direct trauma. Most dislocations are posterior and are clinically evident. The patient is in a lot of pain, the affected thigh is shortened and adducted, and there is extreme pain on motion of the hip. The diagnosis is confirmed by hip x-rays. Look at these carefully as fractures of the acetabulum and proximal femur may also be present. Urgent closed reduction using adequate analgesia or anesthesia is usually successful. Immediately after reduction stress the hip to determine how stable it is in the acetabulum. A hip that redislocates easily on stress testing may have an associated acetabulum fracture. Immediately after reduction, obtain a good quality AP radiograph of the pelvis and compare the normal hip to the injured hip. Joint space widening is caused by interposed fragments of bone or cartilage. Arthrotomy and joint debridement is indicated to remove debris in the joint. Hip arthrotomy is approached from the same direction as the dislocation. If the acetabulum is fractured and the hip is unstable, treatment in traction or by open reduction internal fixation is individualized and referral may be the best option.

Children under six may be more prone to redislocate, so many surgeons place them in a spica cast for a month. Older children may be treated with bed rest or crutches for the first month. Avascular necrosis of the femoral head occurs in approximately 10% of cases.

Femoral Shaft Fractures

These fractures tend to have good outcomes. Most come from low impact injuries and the majority of patients are under age 7. They line up well in traction and they heal well. Up to 2.5 cm. of shortening is corrected by overgrowth of the femur. Immediate treatment in a hip spica cast is an excellent option for the majority of patients. This allows the patient to be cared for at home.

Diagnosis

It does not take a doctor to diagnose this fracture. But a wise doctor will examine the patient for other injuries, and splint the patient for comfort before X-rays are taken. Shock is not caused by a femoral shaft fracture, so look for other causes like a ruptured spleen. The x-ray should include the hip and knee on the same side unless you want to treat a patient until his femur heals but then discover that you missed a femoral neck fracture or a hip dislocation.

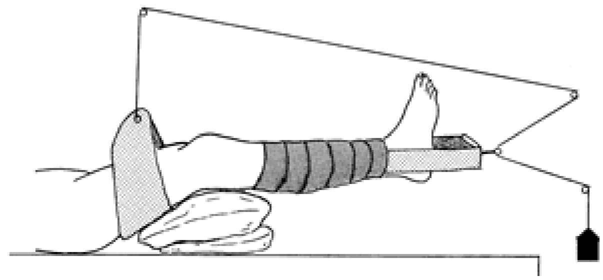
Treatment

The traditional treatment for femoral shaft fractures in infant, children and adolescents is traction until the fracture becomes sticky followed by a hip spica cast until the fracture heals. For younger patients, immediate spica cast application and discharge to home has become standard in recent years. Operative treatment is used increasingly in some countries, but it is driven by the goal of allowing patients who are older or heavier than is considered ideal for early casting to go home after a short hospital stay. Operative treatment is not without complications and since non-operative treatment works well prior to growth plate closure it is recommended by the author.

Traction

Traction for two to four weeks until the fracture is sticky followed by a hip spica is a traditional and reliable method of treatment. Skin traction may be used in children under 12kg. However the use of skin traction with the hips flexed 90 degrees and the legs suspended vertically (i.e.

Bryant's or "gallows" traction) can cause neurovascular compromise and limb loss and is to be abandoned. Split-Russell skin traction is safer: (http://www.steinergraphics.com/surgical/006_17.1.html).



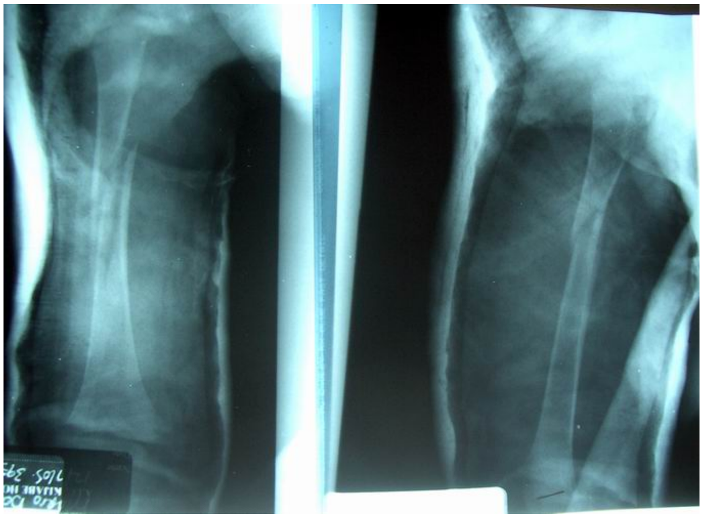
Older children do well in 90-90 skeletal traction with the hip and knee flexed 90 degrees. Distal femoral placement of the traction pin is preferred as it applies traction across the fracture site without placing traction forces across the knee ligaments. A pin placed in the proximal tibia risks injury to the adjacent tibial tubercle growth plate which may cause growth disturbance. Start with traction equal to 10-15% of the patient's body weight for skin traction (5 kg. is the maximum safe for adults per the WHO, less for children) and 15% for skeletal traction. If your hospital has a portable x-ray unit, take films the next day to see if the fracture position is adequate. In high fractures of the shaft near the lesser trochanter, the proximal fragment flexes due to muscular forces and the distal fragment will need to be brought into alignment with it by flexing the hip. 90-90 traction works well for these fractures.
You may measure the length of the leg in traction with a tape measure from the greater trochanter to the joint line of the knee. Compare the length of the injured to the normal leg. If it is more than 1.5 cm. short, add a small amount of traction and re-measure the next day. If you use X-rays to determine how much the fracture overlaps, be sure the x-ray is shot at a true perpendicular to the femur or the spatial relationships of the fracture ends will be skewed.

Early Spica Cast Application

Satisfactory outcomes may be gained by treating selected patients with an immediate spica cast. Though various age and weight criteria have been proposed by different authors, there is little evidence based data to support specific indications. This author recommends that you accept less than 20 degrees of posterior bowing or 30 degrees of anterior bowing (the normal femur has a 10 degree anterior bow) and less than 10 degrees of varus or valgus angulation and less than 2.5 cm of shortening. Exclude patients with open fractures, chest or abdominal trauma, unacceptable shortening, and obese patients. Higher impact fractures cause more periosteal stripping and fracture shortening. If the initial x-ray shows more than 3.0 to 3.5 cm of fracture shortening, it will be difficult to maintain this fracture at adequate length so initial traction until the fracture begins to consolidate is recommended. A patient who weighs more than 40 kg., and who is older than 10 is treated in traction until the fracture is sticky before applying a cast. Immediate casting may be accomplished on a patient who is awake, though ketamine is often used.
The cast should be applied with attention to detail. Though larger children may be done on a standard fracture table, it is better to have a carpenter build a child sized fracture table. This consists of a padded box for the upper torso with a length adjustable sacral support with post. Place a folded towel on the abdomen and lower chest to allow for more space in these areas, and then remove it after the cast is applied. Place two

layers of stockinet over the torso so that padding may be pulled over the edges of the cast. Place a strip of felt around the upper torso where the cast will stop, and another over the sacrum. Then apply cast padding followed by plaster around the torso.

Next apply a below knee cast (the foot should be left out). Apply traction to the fracture by pulling on the below-knee cast with the hip abducted 20 degrees. Then apply plaster to bridge the cast from the knee to the torso. Plaster should extend behind the greater trochanter to the buttocks to avoid having the patient slide out the back of the cast. As the plaster hardens, mold both the anterior and lateral thigh to correct for varus and anterior angulation. When the cast hardens, the lateral thigh should be flat. Then abduct the opposite hip moderately to enhance hygiene and apply plaster stopping at either the knee or ankle. Reinforce the cast with a broom stick plastered between the thighs. Also reinforce the cast with 5-10 layer strips of plaster placed obliquely across the anterior and posterior hips at the weak point where the leg cast attaches to the trunk. Finally, trim the cast around the perineum and sacrum and then check for adequate padding on the cast edges before plastering the stockinet to the cast. Every time you finish any cast it is a good idea to inspect the cast critically asking yourself how you might pad or alter if it were applied to you or one of your family members.



Obtain AP and lateral x-rays of the fracture with care to center the film at the fracture site. Rotate the patient if needed so that the films are shot true to the AP and the lateral planes. If needed, the cast may be cut and wedged to correct angulation. Shortening over 2.5cm. indicates the need to abandon the cast and put the patient in traction. Teach the parents to inspect the skin daily for irritation.

Body casts may be the cause intestinal obstruction with projectile vomiting (Cast Syndrome). This may occur weeks after the cast is applied. Explain to the parents that if this occurs they must urgently return with the patient for cast removal.

Femoral Shaft Fractures with Special Situations

Children under 6 months of age: Femoral shaft fractures may be treated with an immediate spica or a Pavlik harness. For children under 2-3 months of age, treatment with triple diapers or even non treatment is acceptable as these fractures heal quickly and remodel well.

Infants with fractures at birth: osteogenesis imperfecta may be the cause. Obtain an AP x-ray the whole baby and look for other fractures.

Child Abuse (Battered Baby Syndrome): Children under three years of age should be evaluated for child abuse. First obtain a careful history from all care givers. If questions of etiology remain, get an AP x-ray of the whole child to look for other fractures.

Pathologic Fractures:

Chronic bacterial osteomyelitis is the most common cause of pathologic femoral shaft fractures in children in Africa. Slow healing is the rule, and non-unions may ultimately lead to an amputation. Mycobacterium and fungi may also cause bone infections with subsequent fractures. Other causes of pathologic femur fractures include primary bone sarcomas, Ewing's sarcoma, leukemia, osteogenesis imperfecta, rickets, benign bone tumors and simple bone cysts. Benign bone tumors and simple bone cysts may destroy bone and expand the cortex, but their sharply defined border implies a slow growing benign process. Most will heal with non operative treatment. Abnormal anatomy of the whole femur is common in patients with rickets and osteogenesis imperfecta. The femoral shaft may be bowed, and the hip may be show a varus deformity. Also look for evidence of prior healed fractures and abnormalities of the growth plates. A high index of suspicion for cancer should be raised by a low impact fracture through an ill defined bone lesion with multiple "worm holes" present, or a fracture through periosteal new bone formation especially in a patient without a discharging sinus.

A chest x-ray, CBC, blood smear, bone biopsy and cultures may help to obtain a diagnosis in difficult cases. Treatment is individualized according to the underlying etiology.

Fractures of the Distal Femur

Supracondylar Fractures: These transverse fractures occur above the insertion of the gastrocnemius so that muscular forces tend to angulate the fracture with the apex posterior.

When this is seen, the fracture may reduce in 90-90 traction (in this fracture you *should* use a traction pin across the proximal tibia) or in a cast with the knee flexed. Undisplaced fractures may be treated in a spica or a non weight bearing long leg cast with the knee slightly flexed. After casting get x-rays weekly for 3 weeks to observe for fracture displacement. Because of the proximity to the knee, more rigid criteria for reduction are necessary to avoid permanent knee dysfunction. If the fracture cannot be reduced and held in less than 10 degrees of varus, valgus or posterior angulation and in less than 20 degrees of anterior bow, then open reduction and internal fixation is indicated. Remember not to cross the growth plate with hardware other than a temporary smooth pin to avoid growth arrest.

<u>Fractures Involving the Growth Plate</u>: Undisplaced and minimally displaced fractures may be treated in a cast. However, fractures through the distal femoral growth plate are frequently unstable, and are notorious to cause subsequent growth abnormalities. When the fracture is displaced more than 3 mm, open reduction and internal fixation is recommended. Salter I and II fractures are the most common. These may be internally fixed with crossed smooth pins across the growth plate. Screws or pins directed transverse to the long axis of the femur are used for fixation in Salter III and IV fractures. A non-weight bearing long leg cast is applied for 4-6 weeks. Pins that cross the growth plate are then removed.

Photos courtesy of Bob Greene, MD

<u>Supracondylar Humeral Fractures in Children</u>

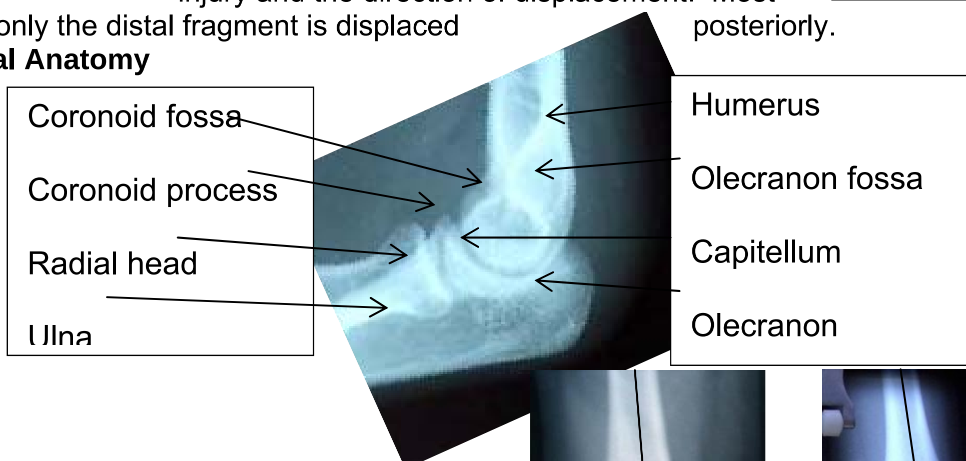
Robert F. Greene, MD

Supracondylar fractures in children are the most common bony injuries you will face in Africa. Without any treatment at all, the children will usually recover with a deformity but some function.

Dangers in Management

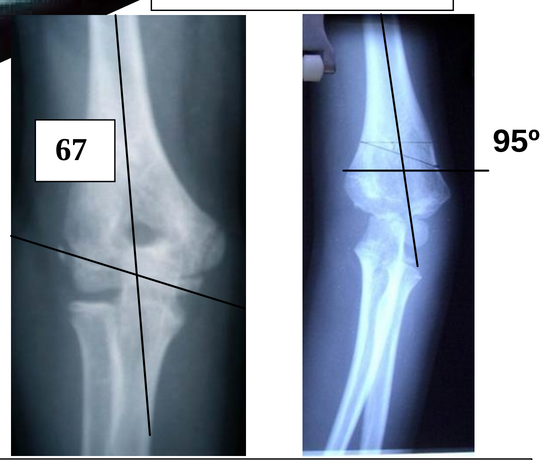
Incorrect treatment, however, can result in terrible deformities and even amputation. For example, tight wrapping, with or without a splint, can result in Volkmann's Ischemic Contracture, a permanent incapacitating complication. Occasionally the ulnar nerve can be damaged from the injury. Therefore a careful neurologic exam is necessary to assess ulnar, median and radial nerve function before any treatment is started, and the circulation should be checked. X-rays are needed to determine the kind of injury and the direction of displacement. Most commonly the distal fragment is displaced posteriorly.

Normal Anatomy



BAUMANN'S ANGLE Lateral angle of capitellar physis with axis of humeral shaft on AP view Normal: 73º ± 6º

Baumann's angle can be used to assess the accuracy of the reduction of the fracture on post-reduction x-ray views.



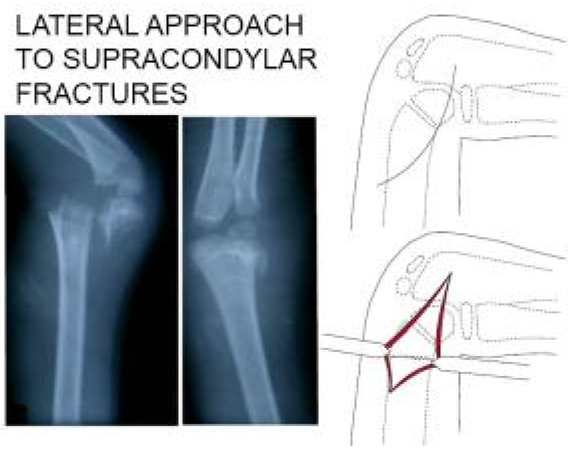
Normal (right) CubitusVarus

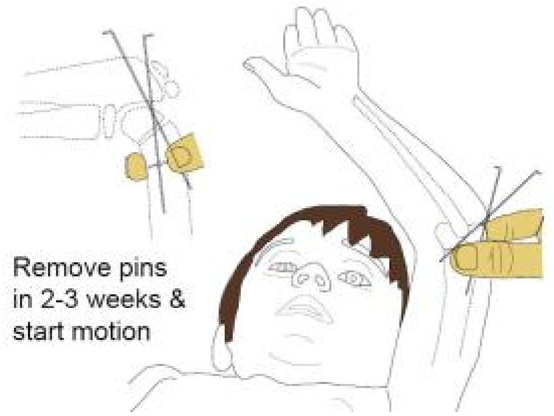
Closed Reduction

Usually the elbow is extremely swollen, making it difficult to palpate the bones or flex the elbow. If surgery is not an option, then a closed reduction may be attempted. The goal should be improved position and alignment, not a perfect x-ray. Under sedation or Ketamine anesthesia, with the forearm in supination, pull on the forearm, then gradually flex the elbow while applying pressure with your thumb over the tip of the olecranon, forcing it forward. Then pronate the forearm. Flexion of greater than 90° is a more stable position, but it also compresses the circulation and can lead to ischemic contracture. A splint may be applied, but there should be no tight wrapping at the elbow. The patient should be observed overnight to watch for signs of nerve compromise or ischemia (severe pain). The patient should be followed-up closely with xrays to check the position.

Open Reduction

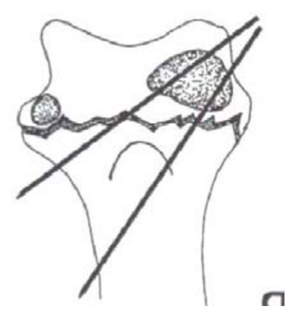
If a C-arm fluoroscopy unit is not available for closed reduction and pinning, then open reduction is a safe and reliable procedure. The author favors a postero-lateral approach with the patient supine. The arm is prepped and draped and held in front of the patient’s face. This is the position of neutral rotation.





Forearm in pronation during procedure and in splint

The nerve at risk on the lateral side is the posterior interosseus nerve. The incision should stay slightly posterior to the lateral condyle as shown. The posterior capsule and periosteum should be incised and elevated off of the fracture site in order to palpate and see the fracture and the humeral shaft. Enlarge the incision proximally, remembering the radial nerve, in order to get your finger in to feel the reduction. The supracondylar fragment can be pulled and pushed up into position and then locked into place by pronating the forearm. The fragment can then be checked for centering over the end of the humerus. It is easy to align the lateral side of the fracture, since it is visible and palpable in the wound. It is more difficult to feel for the proper rotational alignment of the medial condyle. The supracondylar fragment should be tilted anteriorly slightly and then pinned with a Kirschner wire directed through the lateral condyle vertically down into the humeral shaft. This stabilizes the fracture and allows the surgeon to extend the elbow and assess the varus/valgus alignment. If this is satisfactory the rotational alignment can be checked by internal and external rotation. Using the face of the patient as the neutral point, the rotation should be about equal in both directions. Then observing the flat area of the olecranon fossa and comparing it to the direction of the forearm helps assure the surgeon that the rotation is reasonably accurate. Minor rotational malalignment is compensated for easily in a child. If this is satisfactory, a second Kirschner wire is drilled into the lateral condyle starting close to the first pin and directed more medially aiming for the medial cortex of the humeral shaft. When the diverging pins exit the far cortex of the shaft of the humerus, they should not be drilled farther than necessary. Remember that the ulnar nerve is on that side of the elbow. The pins should just exit the cortex and stop there. Observing these precautions there should never



be a nerve injury with this approach. Now the fracture is stabilized and the wound can be closed. The pins are left outside the skin, are bent at a right angle and the extra is cut off. A posterior gutter splint is applied for 2 weeks. Be sure to check neurologic function post-operatively.

Aftercare: The pins are removed at 2 weeks for ages 10 years and under. X-rays at this time will already show abundant callus. For children over 10 years, 3 weeks is recommended. Early removal of the pins and early motion is more likely to result in recovery of full range of motion.

Tendon Injuries

Louis L. Carter, MD

Outline of Chapter

- General Considerations
- Principles of tendon repair
- Tendon repairs
    - Upper Extremity
        - Biceps
        - Extensor tendons
        - Flexor tendons
    - Lower Extremity
        - Achilles

Additional subjects:

- Staged Tendon Reconstruction
- Partial Tendon Injuries
- Flexor Tendon Avulsion—Jersey finger
- Flexor tendon Tenosynovitis

General considerations

After injury and examination tendons should be repaired as soon as possible. Wounds are irrigated and débrided and the tendon ends are identified. If the wound is clean the tendons may be repaired immediately as described below. If this is not possible, the wound can be closed loosely and the repair can be carried out at a later date in a clean wound. (See under Clean Closed Wound Concept in the Chronic Wound chapter) Tendons and nerves can be repaired the following day or even several days later if the wound is irrigated, débrided and loosely closed. It remains a clean wound for a delayed primary repair. A clean wound should never be left open for a later repair. This will allow contamination of the wound.

If the wound is heavily contaminated and the wound cannot be closed initially, tendon repair can be delayed. The wound will require further irrigation and débridement on Days 2, 4, etc. post injury and closure by Day 7. As soon as the wound can be closed the tendons should be repaired.

If the wound has been initially closed, tendon repair may be carried out up to 2 weeks after injury. If later than 2 weeks, repair will be difficult because of muscle contraction and tendon softening. Secondary repair later than 2 weeks post injury is not recommended.

Delayed Tendon Repair with tendon grafts is possible but also not recommended.

Important surgical principles:

1. Function of each tendon
2. How to exam for tendon injuries
3. Knowledge of muscle/tendon relationships in upper and lower extremities
4. Dissection and identification of tendons at surgery
5. Repair of different tendons at different levels
6. Splinting and elevation of extremity after tendon repair—position of extremity
7. Length of immobilization in splint or cast after repair

8. When should therapy and range of motion exercises begin?

Before tendons can be repaired, they must be identified and this requires knowledge of anatomy and muscle/tendon relationships in the upper and lower extremities. Textbooks of anatomy should be in every theatre or operating room for reference. This chapter will cover the repair of commonly injured tendons in the upper extremity and the Achilles tendon in the lower extremity.

Anesthesia and Tourniquet:

Extensor tendon injuries to the dorsum of hand can be repaired under local/wrist or digital block anesthesia. In these cases it still best to use a tourniquet. Method:

1. Infiltrate local anesthesia
2. Place tourniquet over forearm
3. Exsanguinate or elevate hand for few minutes
4. Inflate tourniquet for desired time

This will give at least 20 minutes of anesthesia time. With sedation there will be approximately 40 minutes operating time with local anesthesia. Ischemic muscle pain does not develop as quickly when the tourniquet is placed over forearm tendons in contrast to over arm muscles. Extensor tendon injures at the wrist and above and all flexor tendon injuries require regional or general anesthesia and a tourniquet should always be used.

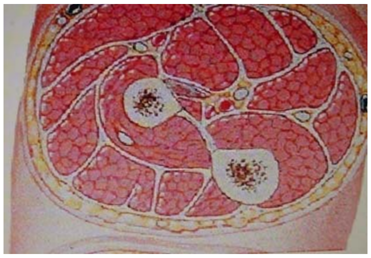
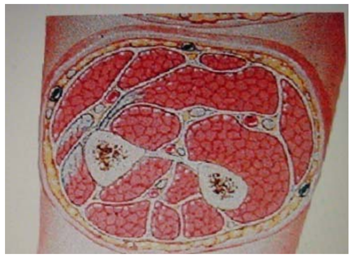
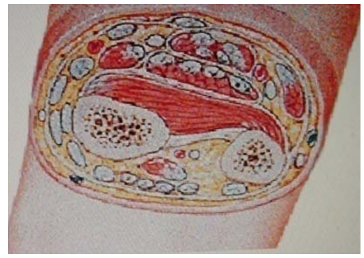
Specific Tendon Repairs:

Biceps Avulsion:

This occurs most often in middle age males with forced extension on a maximally flexed elbow. Findings are ecchymosis in antecubital fossa, weakness of elbow flexion and supination, and abnormal contour and bulging of proximal biceps. Biceps rupture may be incomplete or complete and treatment may be either conservative or operative. Since Brachialis, Brachioradialis and Supinator are intact there will still be weak flexion (70%) and weak supination (60%) with conservative treatment for complete ruptures. Partial injuries can be easily repaired if found early. Complete avulsions can be repaired early with interference screws or suture anchors, if available, to radial tuberosity. If these are unavailable, drill holes may be made in the tuberosity. In each method a strong core weave suture using # 1 or #2 nonabsorbable suture should be placed in the proximal tendon. If drill holes are used, the suture ends can be passed through the tuberosity and tied down posteriorly through a separate posterior incision. The forearm should be pronated to identify the tuberosity through a posterior lateral incision. Exposure requires splitting the common extensor and supinator muscles. Postoperatively, the elbow should be placed in flexion in a cast for 4 weeks. After 4 weeks flexion without resistance may be allowed. Gradual resistance can be added after 6 weeks. (The surgeon should review a detailed description of this procedure and the anatomy before surgery.)

Hand and Forearm

With injuries in the hand and forearm, it is important to know the relationship of the muscles and tendons. After an injury in the hand and forearm the proximal tendon ends retract proximally and lie within the muscles and hematoma. This makes identification difficult in the forearm. It is not uncommon for an inexperienced surgeon to give up trying to identify the proximal tendon ends. Identification of the proximal tendon ends will require proximal extension of the wound, usually in a zigzag fashion, irrigation and removal of the hematoma, and dissection of the tendon ends within the muscles. Wide, extensive exposure is mandatory, both proximally and distally. The apex of each zigzag can be sutured to the skin for retraction and exposure. Finding each tendon not only requires knowledge of anatomy and muscle relationships but also patience as this dissection may take time. The location of the tendons both proximally and distally will depend on the position of the fingers and wrist during injury and also the angle of the injury. Identification of distal tendon ends is easier as the wrist and fingers can be flexed to find flexor tendon ends or extended to find the extensor tendon ends.

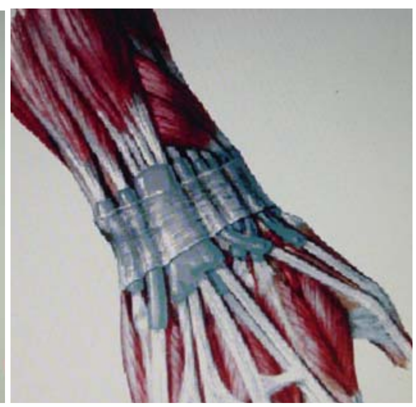




Cross section upper arm Cross section mid arm Cross section above wrist

It is difficult to remember these relationships. An anatomy textbook should be available

<u>Extensor Tendons</u>





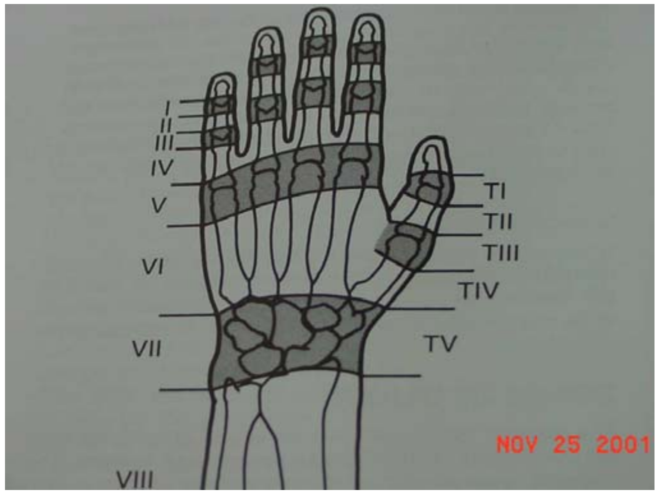

superficial deep wrist and hand snuff box

Anatomy of dorsal side of forearm and hand with extensor tendons—note the four extensors arising from ulna in the deep forearm, from proximal and radial these are APL, EPB, EPL and EI. Also note the 6 compartments at the wrist

Below is a summary of extensor tendons from radial to ulnar, their abbreviation, insertion, function, findings on exam if injured and compartment location at wrist. All are innervated by radial nerve.

Abductor Pollicis Longus (APL)—radial abduction of thumb inserts base of thumb metacarpal; exam--weak radial abduction of thumb metacarpal; first compartment
Extensor Pollicis Brevis (EPB)—extension of thumb proximal phalanx; inserts base of thumb proximal phalanx; exam--weak extension of Proximal Phalanx; first compartment
Extensor Carpi Radialis Longus (ECRL)—extension and radial deviation of the wrist; inserts base of index metacarpal; exam--weak extension and radial deviation; second compartment
Extensor Carpi Radialis Brevis (ECRB)—extension of wrist; inserts base of third metacarpal; exam--weak wrist extension; second compartment
Extensor Pollicis Longus (EPL)—extension of distal phalanx of thumb; inserts base of distal phalanx; exam--weak thumb extension; third compartment
Extensor Indicis (EI)—extension of index finger Proximal Phalanx; inserts into sagittal band; exam--weak extension of proximal phalanx of index finger with fingers flexed; fourth compartment
Extensor Digitorum Communis (EDC)—extension of all fingers; inserts into sagittal band; exam--weak extension proximal phalanx; fourth compartment
Extensor Digiti Minimi (EDM)—independent extension of small finger; inserts into sagittal band; exam--weak extension small finger proximal phalanx with fingers flexed; fifth compartment
Extensor Carpi Ulnaris (ECU)—extension and ulnar deviation of wrist; inserts into base of 5th metacarpal; exam--weak extension and ulnar deviation; sixth compartment overlying ulna

Repair of an extensor tendon is not difficult but it must be done carefully with good exposure. Usually one or two horizontal sutures or a core, weave, suture is adequate. Ideally monofilament nonabsorbable sutures are used if available. Lacerations are common over the dorsum of the hand. Even though extensor tendons in the hand do not retract as extensor tendons in the forearm or flexor tendons, one should extend the wound proximately and distally in order to identify the ends and perform an adequate closure. There are zones for tendon injuries, not only flexors but also extensors. The nine zones for extensor tendon injuries help in determining the proper repair. Below is listed the Zone, suggested repair, splint method, and rehab methods.



Zone 1—Terminal tendon injury over Distal Interphangeal joint and Mallet Injury:

Tendons are thin at this level. If after a laceration the ends are clearly seen, primary repair is done with a running 5-0 or 6-0 monofilament suture, but if difficult to identify, continuous splinting of the DIPJ only for 6 weeks will work well. Closed Mallet injuries involving only the terminal tendon require splinting for 6 weeks with gradual tapering after 6 weeks, allowing progressive exercise periods during the day and splinting at night for 4 more weeks. If there is a bony Mallet, usually a closed fracture at the insertion of the extensor tendon, and no subluxation of distal fragment, splinting alone is sufficient for 6 weeks. If there is volar subluxation of the distal fragment of the distal phalanx, there are several methods of reducing and holding the reduction with K-wires for 6 weeks.

Zone II—Between Distal Interphalangeal Joint (DIPJ) and Proximal Interphalangeal Joint (PIPJ)

The terminal tendon and lateral bands may be divided: tendon is very thin and repair with fine monofilament running or horizontal mattress suture

Splint and rehab as Zone I.

Zone III—over the Proximal Interphangeal joint and Central Slip insertion:

There should be a high degree of suspicion with any injury over the PIPJ since the slightest and most insignificant laceration can partially divide the central slip. The patient may initially extend the PIPJ with the lateral bands, but if the injury is missed and untreated, the lateral bands will in time slip to the volar side and become flexors rather than extensors. A boutonneire deformity will result with a PIPJ flexion deformity and an extensor lag. If the laceration is through the tendon, a core suture of 4-0 monofilament as discussed under flexor tendon injuries can be used. If the injury is at the insertion into the middle phalanx or if central slip avulsed, then one may have to place the suture through proximal portion of the middle phalanx. This can be done with bone anchors or with a drill hole through the middle phalanx.

Technique for anchoring suture to bone without anchors: Use a .035 or .045 inch K-wire to drill through bone where you wish to anchor tendon. Then pass a 20 gauge needle through drill hole, pass a 4-0 monofilament suture through needle, remove needle, pass suture ends next to base of middle phalanx and weave suture through tendon and anchor the tendon down to bone.

Splint or pin PIPJ in extension for 6 weeks, allowing DIPJ and MPJ freedom to flex

In delayed injuries to Central Slip with extensor lag (incomplete extension of middle phalanx), if the PIPJ can be passively extended, then splinting of PIPJ for 6-12 weeks is usually satisfactory. To eliminate the compliance required in wearing a splint for either acute or delayed injuries, a K-wire across the joint for 6 weeks may used in place of a splint.

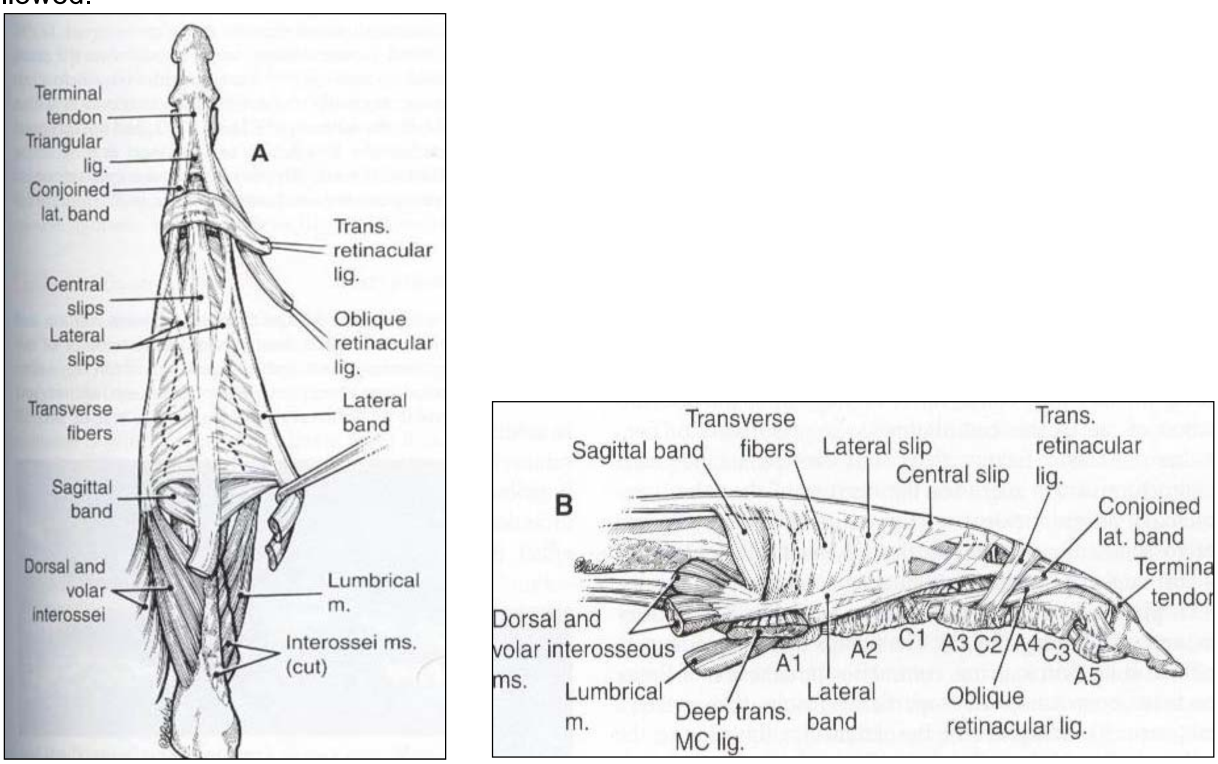
<u>Zone IV</u>—<u>over proximal phalanx</u>

Repair with horizontal mattress sutures. Splint the PIPJ and DIPJ in extension for 6 weeks.

<u>Zone V</u>—<u>over Metacarpal Phalangeal joint</u>

This injury may involve the joint. Several horizontal mattress sutures or core sutures are adequate. Index and Small fingers have two tendons with the EDC always the radial tendon. Repair both tendons. Beware of lacerations over MPJ as these may be from a clenched fist or human bite injury. These may or may not lacerate the tendon but be aware of possible metacarpal phalangeal joint bacterial inoculation. Unless recognized, this injury may lead to a septic joint and/or severe cellulitis. X-rays maybe necessary to rule out foreign body, as a tooth, within the joint. Copious irrigation and antibiotics are required.

After tendon repair, the MPJ should be held in extension at 0°with the wrist extended 20° for 2-3 weeks. Then every 2 weeks the MPJ is gradually flexed and splinted with the wrist still held in 20° extension. After 6 weeks the splint can be removed with increasing range of motion allowed.



Dorsal tendon apparatus and intrinsics in extensor tendon Zones I-V
Note annular pulleys 1, 3 and 5 on volar side are over joints

<u>Zone VI</u>—over dorsum of hand

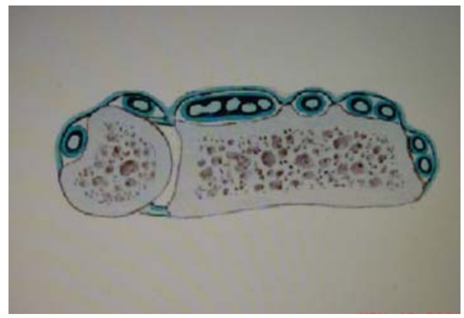
Because of juncturae (fascial connections between the extensor tendons) there may be weak extension of the finger even if proximal extensor to finger is lacerated. In this Zone tendons retract and proximal extension of wound maybe necessary to find the proximal end for repair. Care must also be taken when evaluating EPL injuries as intrinsic tendons to thumb (APB and AdP) will give weak extension when the EPL is divided. Repair with horizontal mattress sutures or a core monofilament 4-0 suture.

Splint the hand and fingers as for Zone V.

If injuries above are not extensive in zones above, then repair may be carried out under local anesthesia. If possible a forearm tourniquet should still be used to give a bloodless field.

Zone VII—over wrist joint and extensor retinaculum Knowledge of extensor compartments is important. There are six compartments.

Extensor tendon compartments



Cross section from ulnar to radial

Compartment 1—APL and EPB are usually in same compartment but maybe in two separate compartments. (This is something one must be aware of when treating tenosynovitis of First Dorsal Compartment or de Quervain's Syndrome as one must release both compartments if present.)

Compartment 2—Long extensor tendons to wrist, ECRL and ECRB. These large tendons will retract when divided. Repair with a 2-0 or 3-0 core suture (a braided suture may be used). Care must be taken to hold wrist joint in extension after repair to take tension off repair while other injuries and skin are repaired.

Compartment 3—Long extensor to thumb, EPL. It courses around Lister's tubercle with the tubercle as a fulcrum. This tight compartment must always be released for repair and EPL should be left subluxed radially and lying over second compartment after repair.

Compartment 4—EDC tendons are superficial with the EI (EIP) deep. The Extensor Indicis can usually be identified deep to the other tendons with a more distal muscle belly. Usually the retinaculum must be opened for repair and then partially repaired to prevent bowstringing. Either horizontal mattress sutures or a core suture technique may be used for repair of these tendons.

Compartment 5—EDM: open retinaculum, repair tendon, and leave retinaculum open, repair with horizontal mattress

Compartment 6—ECU: over ulna, requires strong core suture for repair and repair of overlying sheath if possible to prevent subluxation

Tendon repairs of the wrist extensors in Zone VII require splinting of the wrist in 20-30° extension for 6 weeks. For finger extensor injuries at the wrist, the wrist is held in 30° and the MPJs are splinted (blocked) in 0° extension for 4 weeks with a volar splint. The fingers are allowed to begin gentle Active Range of Motion (AROM) after 4 weeks but the splint is worn until 6 weeks post op. The IPJs (PIPJ and DIPJ) are included in the splint and the patient encouraged to exercise these joints.

Zone VIII—distal forearm

Anatomical relationships are important to know in order to identify the injured tendons. Repair may be at the musculotendinous junction. Four extensor tendons originate on the ulna and course from ulna to radial side and deep to the long extensors. Beginning proximately, these are APL, EPB, EPL and EI. Repair the tendons with a tourniquet and IV Regional, Axillary Block or general anesthesia. Splint with the wrist extended and MPJs as under Zone VII

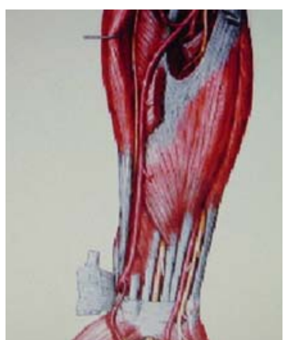
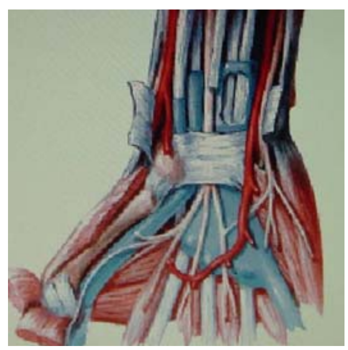
Zone IX---proximal forearm: Dissect tendons out of muscle for repair. In proximal forearm the muscle will need to be approximated.

<u>Extensor Tendons Zones for Thumb</u>:
Zone I and II are similar to Zone 1 and IV in the fingers
Zone III is similar to Zone 5.

The EPB inserts to the proximal phalanx base on radial side. There is no sagittal band. EPL is ulnar and inserts at base of distal phalanx (no middle phalanx in thumb).

Zone IV is similar to Zone VI: Repair both EPB and EPL
Zone V is through extensor retinaculum described above

<u>Flexor Tendons</u>


forearm: superficial deep
Wrist: superficial deep
Anatomy of the volar or flexor side

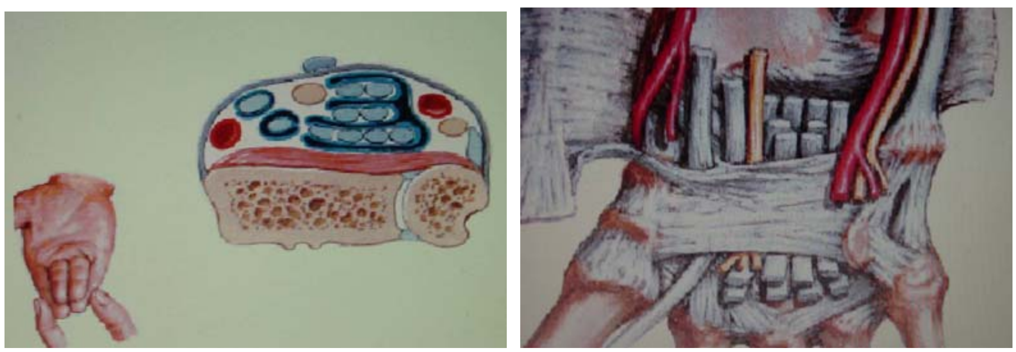
Flexor tendons at the wrist from ulnar to radial: function, insertion, exam, innnervation

<u>Flexor Tendons from ulna to radial at the wrist:</u>

Flexor Carpi Ulnaris (FCU)—strong flexion and ulnar deviation of wrist; inserts on base of 5th metacarpal; exam--weak wrist flexion

Flexor Digitorum Profundus (FDP)—flexion of DIPJ and distal phalanx; lies deep in forearm and just volar to Pronator Quadratus and Interosseous Membrane; inserts at base of distal phalanx; ulnar 3 slips conjoined and function together; exam-- lack of flexion of DIPJ when middle phalanx stabilized

Flexor Digitorum Superficialis (FDS)—flexion of PIPJ and middle phalanx; note in the figure below the orientation of the tendons pass through carpal canal and under Transverse Carpal Ligament; insert on base of middle phalanx; exam—lack of flexion of middle phalanx when other fingers held flat in extension.



Anatomy and position of FDS tendons and relationship of FDS and FDP in relation to PL and Median Nerve

Palmaris Longus (PL)—superficial and lies over Median Nerve and is a wrist flexor. A high percentage of injuries to PL will also injure Median Nerve. Even though one might not repair PL, careful examination must be carried out to rule out median nerve injury.

Flexor Pollicis Longus (FPL) lies deep between PL and FCR; flexes thumb IPJ and distal phalanx; exam--weak flexion of distal phalanx when proximal phalanx stabilized.

Flexor Carpi Radialis (FCR)—superficial and flexes wrist; inserts into base of second metacarpal; exam--weak wrist extension and when wrist is flexed

Brachioradialis (BR)—Elbow flexor lies deep and radial to FCR and flexes the elbow; inserts into distal radius; exam—may not feel contracted BR with elbow flexion. Radial nerve lies just ulnar to BR (between BR and ECRL) in forearm and branch of radial nerve lies superficial to the BR insertion. Radial artery lies between FCR and BR

It is important to realize muscles involved in the following functions:

- Thumb palmar abduction—Abductor Pollicis Brevis, APB—median nerve
- Thumb MPJ flexion---Flexor Pollicis Brevis, FPB—median and ulnar nerve
- Thumb adduction—Adductor Pollicis, AdP—ulnar nerve
- Finger MPJ flexion, abduction, adduction—Interosseous and Lumbrical muscles—only two radial lumbricals are innervated by median nerve
- Finger extension at DIPJ and PIPJ –intrinsic tendons

<u>Notes on flexor tendon injuries</u>:

Ulnar Artery and Nerve are radial to FCU with artery volar and nerve dorsal. Any injury to FCU or flexor tendons will likely injure these structures.

There are 10 structures in the Carpal Tunnel: All FDS and FDP tendons (8), FPL and Medial Nerve

Approximately 20% of individuals do not have an independent FDS slip to the small finger

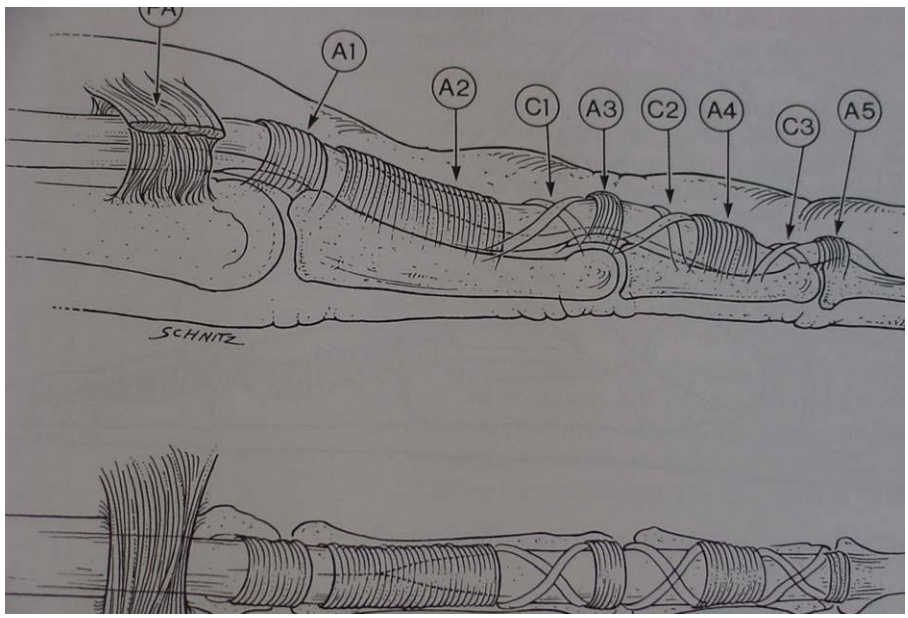
Approximately 20% of individuals do not have a PL

All long flexors are ulnar or dorsal (deep) to Palmaris Longus. Any injury at wrist ulnar to Palmaris Longus may injure all flexor tendons to the fingers.

Flexion of MPJ is through intrinsic tendons and not the long flexors. On exam, be aware of patient who flexes proximal phalanges only as distal flexors may be divided.

The palmar cutaneous branch of median nerve lies superficially between the PL and FCR tendons at wrist.

Before discussing flexor tendon repairs, it is important to discuss the pulley system. There are 5 annular pulleys.



A-2 and A-4 are over phalanges and must be preserved for complete finger flexion

A-1—located over MPJ (divided in trigger fingers)
A-2—located over Proximal Phalanx and <u>must be preserved for full flexion</u>
A-3—located over PIPJ, usually divided in tendon repairs
A-4—located over Middle Phalanx and <u>must be preserved for full flexion</u>
A-5—located over DIPJ—can be divided for Zone I repairs

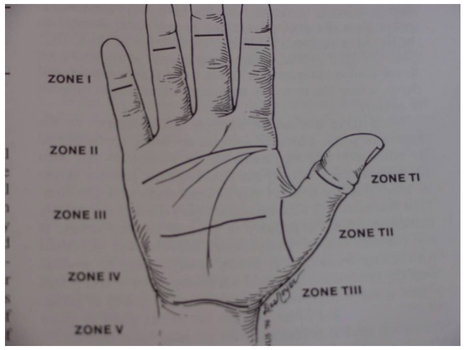
Cruciate pulleys between annular pulleys allow flexion. If either A-2 or A-4 is completely divided, they should be repaired with a tendon graft (portion of unrepaired FDS or slip of EDM or PL).

Thumb has three pulleys:

A-1—located over MPJ (divided in trigger thumb)

A-2 or oblique—located over Proximal Phalanx and <u>must be preserved</u>
A-3—located over IPJ

<u>Zones in the fingers and repair of tendons in each Zone:</u>



Flexion tendon zones

<u>Zone I</u>—from A-4 pulley to insertion FDP—repair FDP with core suture. May need to attach tendon end to base of distal phalanx with an anchor or with drill holes or with sutures passed around the phalanx and through the nail bed on either side.
<u>Zone II</u>—from A-1 pulley to FDS insertion under A-4 pulley, Fibrous Osseous Canal or "No Man's Land"-- repair only profundus tendon if both are lacerated as there is not enough room for excursion if both tendons repaired. The FDS is excised.

With Zone II injuries, one should explore injury through a window in the tendon sheath between A-2 and A-4. A-3 and cruciate pulleys can be sacrificed to provide a window for repair. If absolutely necessary, the distal half of A-2 and the proximal half of A-4 can be divided in order to retrieve the tendons and perform the repair.

Many injuries in this Zone occur with the fingers flexed and the proximal end of FDP may retract into the palm and the distal end may retract under A-4 pulley. Exploration in the palm will likely be necessary. One may flex the wrist and MPJ and look for the proximal end of the FDP. Blind grasping for the tendon end is discouraged. It is better to identify the tendon with a distal palm incision. A core suture can be placed in the proximal FDP and the suture passed under A-2 pulley and the repair carried out between A-2 and A-4 pulleys. If the FDS is intact then the proximal end of the FDP should be passed back through the split in the FDS if possible. If the FDS has been lacerated, it is excised. If one slip of the FDS is intact, it may be left and the lacerated slip excised. The distal tendon end may be retrieved distal to A-4. A core suture may be placed distal to A-4 and the end passed proximally under A-4 for repair in window described above, between A-2 and A-4.

<u>Zone III</u>—from distal end of Transverse Carpal Ligament to A-1 pulley, area of Lumbrical muscles, one may repair both tendons but <u>best to repair</u> profundus only and FDS left unrepaired.

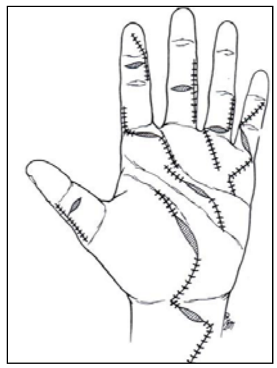
The proximal tendon may or may not retract according to whether or not the lumbricals are divided. Usually the Lumbricals are divided and the laceration will need to be extended proximately through the Transverse Carpal Ligament and into the forearm. The proximal end may retract into the forearm and into its muscle belly where careful dissection is required to identify it. (Note: divide Transverse Carpal Ligament on the ulnar side in line with the 4th ray so that the motor branch of the Median Nerve is not injured.)

<u>Zone IV</u>—beneath Transverse Carpal Ligament—divide ligament and repair only profundus.

<u>Zone V</u>—proximal to Transverse Carpal Ligament in forearm—may repair both if sharp, clean laceration but repair of the FDP only is adequate. It is important to know muscle relationships and remove hematomas so that proximal tendon ends can be found.

<u>Incisions in the hand and fingers</u>:

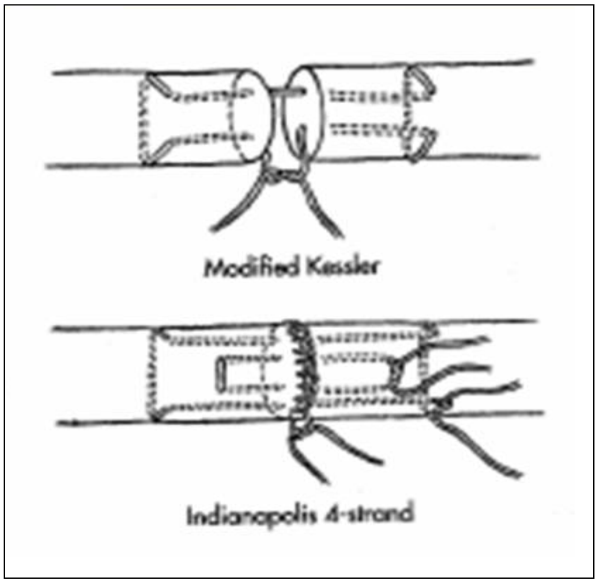
Incisions for tendon exploration in the fingers can either be a Bruner zigzag incision (small finger below) or a mid-lateral incision or a combination of both. The Bruner incision extends from the end of one crease to the opposite end of the next adjacent crease. In the palm these zigzag incisions can be continued.

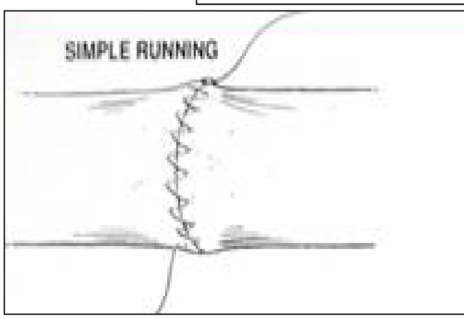


Finger and hand incisions

<u>Flexor tendon repair technique</u>:

Repair flexor tendons with core or weave, suture using 3-0 *or 4-0 braided non-*absorbable suture. A braided suture holds best and does not slip. A Kessler or Modified Kessler suture core techniques are the easiest to use. It is best to tie the suture inside the repair as in the modified Kessler repair so that excursion is not interfered with. An additional horizontal mattress suture increases the strength of the repair and gives 4 strands across the repair site as in the Indianapolis repair below. The epitenon should be repaired with a running suture of 5-0 or 6-0 monofilament suture. This also increases the strength of the repair and reduces gapping and bulk. Different techniques have been used but a running suture is easy and works well. (See below) It may also be locked.



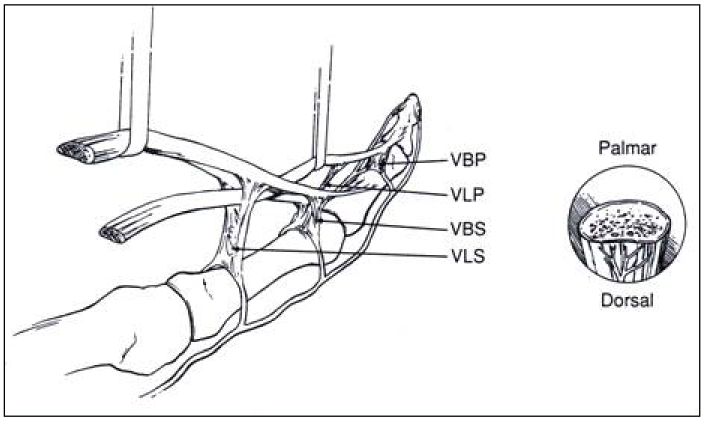


Modified Kessler puts the suture inside the repair site. Additional horizontal mattress suture and epitendinous suture add considerable strength to the repair.

During repair, the tendon surface should not be grasped. The tendons are held by grasping inside the end of the tendon with small toothed forceps. Once the tendons are approximated in preparation for repair, one may pass hypodermic needles through the tendons and into surrounding soft tissue. This prevents the tendon ends from retracting and allows tendon repair without the need to grasp and pull on the tendon. Grasping the outside of the tendon damages the epitenon and leads to adhesions.

<u>Tendons healing</u>:

Tendons heal through direct vascular supply at musculotendinous junctions, their vinculae and through synovial diffusion. They can also receive blood supply through adhesions but these are not desirable.



Blood supply from vinculae and bony attachments and diffusion from synovial sheath (in blue above)

Vinculae should be preserved if possible during tendon repair

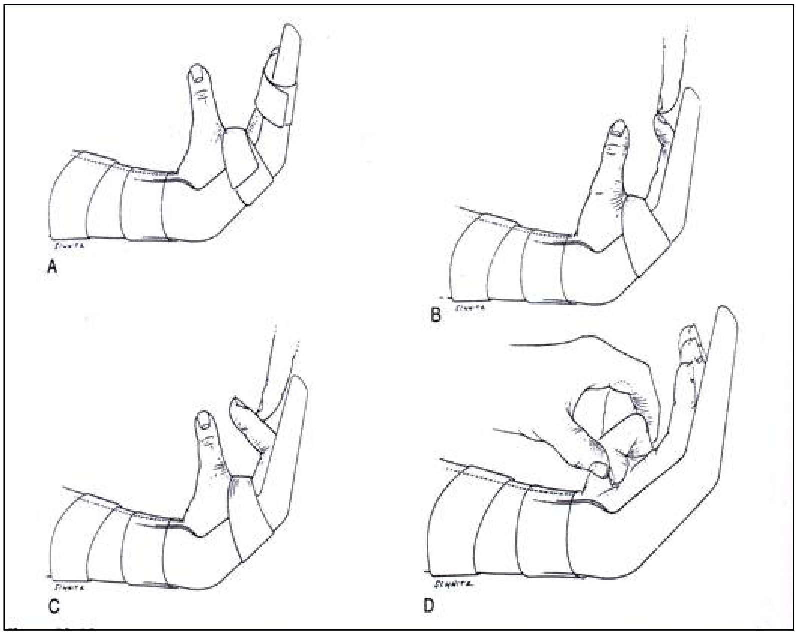
<u>Splinting and exercises</u>:

Weeks 1 and 2—extension blocking splint with the wrist flexion at 45°,
finger flexion 80°-90° at MPJ with IPJs extended.
Allow passive flexion of fingers (Duran technique)

Weeks 3 and 4—wrist flexion 15-30° with fingers in same position
Same passive therapy

Weeks 5 and 6—wrist neutral with MPJ at 45° and fingers in same position
May begin gentle active motion of fingers at 5 weeks without resistance

Weeks 7 and 8—remove splint and allow further gradual range of motion



Duran Technique: controlled passive motion
The fingers are passively flexed and active extension allowed
No active flexion is allowed—need close supervision first week

Splinting and therapy may be individualized according to age, intelligence, compliance, location and realistic opportunity for follow-up. Often the patient is not seen for weeks and a realistic approach is necessary. In centers where there experienced therapists and one expects excellent patient compliance, both tendons may be repaired in Zones II through V and a more aggressive active motion therapy program used, but this is rarely possible and should be discouraged. Children should be splinted for 4 weeks without active or passive range of motion. Children will usually recover full range of motion.

With flexor tendon injuries in the hand and fingers, care must be taken to clearly identify nerves and vessels and repair each one. Whether or not an individual artery is repaired is determined by an Allen test.

Staged Tendon Reconstruction:

This two to three stage technique is a secondary procedure and is used when the tendons are damaged beyond repair or when after a previous repair there are severe adhesions. This technique requires the use of a silastic rod, Hunter Rod, for the initial stage. The reader is referred to hand surgery textbooks for further information. This technique requires close follow-up, an excellent therapist and is not recommended in most situations.

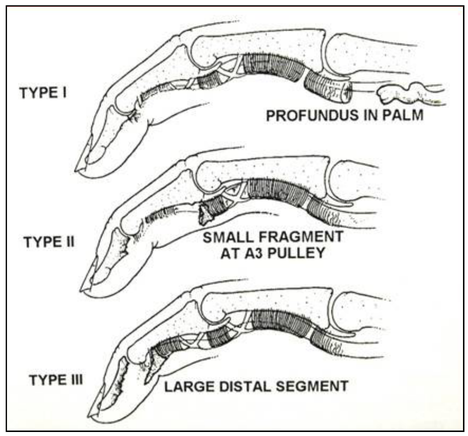
Tendon Ruptures:

Occasionally a tendon repair will rupture accidentally a few days after repair or when dealing with a non-compliant patient. If this was an accidental rupture, these ruptures can be repaired immediately with fairly good results. After a few days repair will be difficult.

Partial Tendon Lacerations:

Occasionally, a patient may present with a partial tendon laceration. This should be suspected if flexion is weak, painful and incomplete. If the tendon laceration is greater than 50% of the diameter, routine repair with core sutures should be done. If less than 50%, nothing is required other than trimming or tacking down the cut edges with 5-0 or 6-0 epitendinous suture to prevent catching or triggering on a pulley edge. Exercises are generally begun sooner in these injuries

Flexor Tendon Avulsion: This is a closed injury with avulsion of the Flexor Digitorum Profundus at its insertion at base of distal phalanx. This should be suspected with any enlarged and tender finger after a rugby match or rock climbing. This is often called a "jersey injury" from catching a finger, often ring finger, on a jersey with forced extension of the distal phalanx while there is maximum FDP flexion. Suspicion with early recognition in a swollen finger after closed trauma is most important. There are four types:



Avulsion injuries: Types I-III

I—FDP retracts into palm: early recognition is important, repair within 1 week
II—FDP retracts to PIPJ or distal edge of A2 pulley with or without small bone fragment (may have vincula still intact), may still be able to repair at 4-6 weeks
III—FDP with larger fragment of distal phalanx retracts to A4 pulley, may be able to repair at 6-8 weeks
IV—FDP and small fragment of distal phalanx retract but separately and both need repair urgently as FDP may retract into palm—unusual injury

Flexor tenosynovitis:

This is a closed infection in the tendon sheath of the fingers. The findings are Kanavel's Four Classic signs: swollen finger, tender along the flexor tendon sheath, flexed posture and most important, significant pain when the finger is passively extended. If seen early, the tendon sheath can be opened distally at the DIPJ crease and proximally at the distal palmer crease and the sheath irrigated from distally to proximally. In most cases, these fingers will be seen very late and the tendons will be destroyed. The best treatment in these late cases is ray amputation of the finger. The patient may not agree to this radical treatment but if the diseased finger is left, the remaining fingers will become stiff and lose range of motion. If the finger is amputated, the other fingers will usually regain full range of motion with an excellent functional outcome. Most people never notice the amputated finger if a good ray amputation has been carried out.

Flexor tenosynovitis   Late delayed case as is commonly seen

Note posture and swelling and passive extension will cause severe pain

Achilles Tendon Injuries

Acute open injuries can be repaired with several core weave sutures as in flexor tendon injuries or a Krachow whip stitch with a large braided non-absorbable suture—probably the largest available in the hospital. It is best to expose the tendon through a medial incision. The ankle may then be casted in plantar flexion for 6-8 weeks. Acute closed ruptures can be treated open or closed with equally good results in recent literature studies.

Summary

Tendon injuries require early identification and repair. Even in major centers excellent results are difficult to achieve with flexor tendon injuries in the hand since these require special and frequent therapy sessions and exceptional patient compliance. Any severe trauma or crushing type injury further compromises the final result. If therapists are not available to follow the patient on a bi-weekly or weekly basis, then the surgeon must learn basic therapy techniques in order to care for his patients.

Flaps for Wound Coverage

Louis L. Carter, MD

This chapter will cover the flaps commonly used for wound coverage and burn reconstruction for upper and lower extremity reconstruction when microvascular reconstruction is not possible. There are many flaps and the ones covered here are the ones most commonly used. These include:

- Parascapular
- Latissimus Dorsi—also used to reconstruct Biceps tendon
- Cubital Artery
- Radial Forearm, antegrade and retrograde
- Groin
- Superficial Inferior Epigastric
- Tensor Fascia Latae
- Saphenous
- Gastrocnemius
- Soleus
- Cross Leg Flap
- Sural Artery or Reverse Leg Flap
- Dorsalis Pedis Flap
- Medial Plantar

Reconstructive Ladder:

With any reconstruction, the reconstructive ladder must be followed so that the simplest reconstruction that will give a good result will be used first.

Primary wound closure or delayed primary closures are ideal if possible.

Secondary closure requires sharp excision of the wound and then direct closure or closure with a skin graft or flap. Often the wound has healed by secondary intention and is infected. This is seen when patients present late or are referred from another institution. Some patients with wounds over joints may present with contractures resulting from the secondary healing process.

Healing by secondary intention is not recommended except with the use of the Vacuum Assisted Closure (VAC) or Negative Pressure Therapy. Usually the VAC is used to prepare a wound for closure with a skin graft or flap, but in difficult areas and on special patients, long term VAC use may also allow the wound to heal by secondary intention but in a clean environment. This is a useful technique in pressure ulcers. This technique is described in detail in the chapter on chronic wounds.

Skin grafts provide a simple and efficient means of reconstruction. Skin grafts do well except over joints. If they must be used over joints, long term splinting is necessary to prevent late contracture. The greater the percentage of dermis in a graft the softer and more pliable it will be and better cosmesis will result. Therefore, full-thickness skin grafts result in a better outcome than split-thickness grafts. Meshed grafts take well and are more reliable than sheet grafts, but the final appearance may not be aesthetically pleasing. In many areas of the body this is unimportant and meshed skin grafts do well.

Local and Regional Flaps will be the subject of this chapter.

Distant Flaps maybe used with or without a microvascular anastomosis, as a cross leg flap.

Microvascular reconstruction will not be dealt with in this chapter.

Blood supply of flaps:

Flaps are either random or axial. Random flaps are supplied by multiple vessels rather than just one. Most skin flaps are random flaps and the length of the flap should equal the width. These flaps may cover small areas and can be further classified as a transposition, rotation, bilobed, etc. flap. Axial flaps have one or two vessels throughout the entire length of the flap. These flaps may be 3-4 X the width as long as the blood supply is in the center of the flap. Axial flaps maybe fasciocutaneous, myocutaneous, or muscle only. Microvascular flaps are axial flaps and may also contain bone. Fasciocutaneous flaps contain the superficial fascia which is superficial to muscle fascia. Blood supply to the skin lies just superficial to the superficial fascia. The best illustration of this is in the lower abdomen where the vessels to the skin, the Superficial Inferior Epigastic Artery and Vein lie just above Scarpa's fascia, the superficial fascia. These vessels can supply the entire abdominal wall skin. All flaps discussed here will be axial flaps and very reliable. A Doppler is an ideal aid to identify arteries and their course.

Mathas and Nahai have classified muscle flaps and fasciocutaneous flap according to their blood supply.

Muscle Flap Classification:

Type I – one vascular pedicle as in the gastrocnemius muscle flap where each head is supplied by either the medial or lateral sural artery

Type II—one dominant pedicle and several minor pedicles as the gracilis muscle which has one dominant pedicle from profunda femoral artery and several minor pedicles off superficial femoral artery

Type III—two dominant pedicles which allow the muscle to be divided in the midline and one half used for a flap. An example is the gluteus maximus muscle with the superior half supplied by the superior gluteal artery and the inferior half supplied by the inferior gluteal artery.

Type IV—multiple segmental vascular pedicles which allows only a small portion of the muscle to be transferred. Sartorius muscle in the thigh and most of the leg muscles are in this category.

Type V—one dominant vascular pedicle from one end and secondary segmental vascular pedicles from the other. The arterial supply may be divided on either end and rotated around the opposite end. Latissimus Dorsi and Pectoralis Major are examples.

Fasciocutaneous Flap Classification:

Type A—Direct Cutaneous—as groin flap

Type B—Septocutaneous, vessels that course between muscles to the fascia—as parascapular flap

Type C—Musculocutaneous, vessels from the muscle to fascia

There is a relatively new type of flap, called perforator flaps, but they will not be discussed here as they are primarily used in microvascular reconstruction.

Even though flap coverage of a wound is a more complex method than skin grafting, flaps offer a number of advantages.

1. Flaps carry their own blood supply

2. Flaps reconstruct an area with “like” tissue
3. Flaps give a cosmetically pleasing appearance
4. Flaps can be used to cover exposed bone and tendons
5. Flap reconstruction over joints after a contracture release eliminates the need for long term splinting
6. Flaps can carry other tissue as bone for reconstruction

Expanders: Skin expansion is an additional method for wound closure, actually a secondary wound closure method using expanded tissue, flaps, adjacent to the wound for advancement and closure.

Principles of flap reconstruction

In most cases surgery is best performed under general anesthesia since skin grafts from a separate site may often be necessary.

It is most important to carefully measure the recipient area before raising the flap.

In most cases antibiotics are given before surgery and occasionally for 24 hours after surgery. In special cases, as in diabetics, elderly, antibiotics may be used longer

The flaps are sutured in place with a Gilles suture, a half buried horizontal mattress suture. The knot is in the normal or non-flap skin with the buried horizontal suture in the dermis of the flap. Ideally the suture is an absorbable monofilament suture that will absorb in time. Braided sutures as Vicryl may be used. This suture technique causes little damage to the blood supply of the flap.

A skin graft to reconstruct a donor defect is either stapled into place or sutured with running absorbable suture, as chromic or Monocryl suture. A wet cotton dressing is applied to the skin graft.

If the skin graft is not meshed, then a drain is left beneath the flap for 24-48 hours. If meshed skin is adjacent to the flap, usually no drain is necessary.

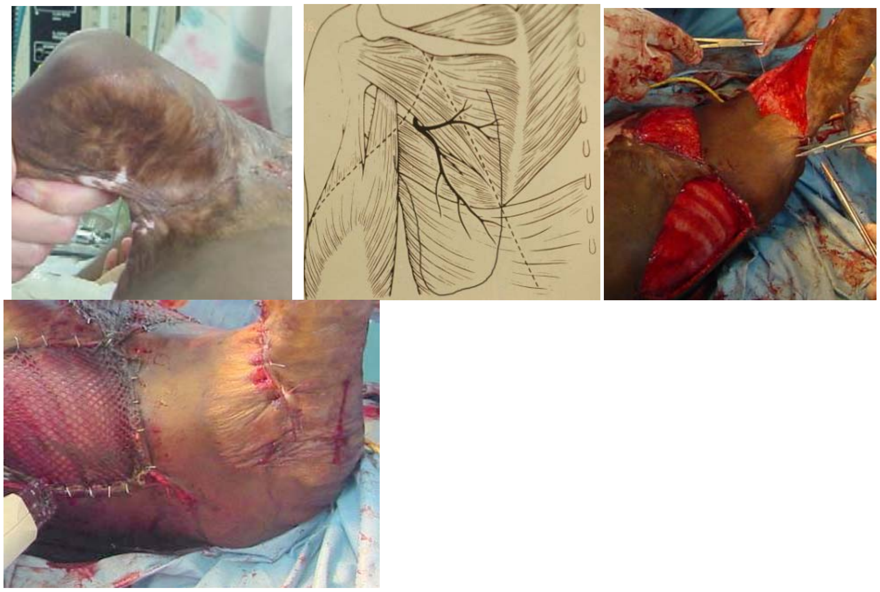
The extremity is immobilized either with a bulky dressing and usually a splint for comfort and to allow the skin graft to take and heal well. remove

Pedicle flaps from a distant location as a groin or SIEA flap will need division. Normally this is carried out at 3 weeks. If the recipient site is severely scarred with questionable blood supply, then the flap can be partially divided at 3 weeks with the remaining pedicle divided at 4 weeks. The flap should not be inset (sutured carefully into the recipient area) until a week later so that no tension will not be placed on the new bridging capillaries supplying the flap. It may be tacked down with a few simple sutures at the time of division. remove

Flaps

(Detailed descriptions of these flaps and many others are found in major textbooks. The indications for these flaps will be found here.)

Parascapular Flap is a reliable and ideal flap for axillary reconstruction. It is an axial fasciocutaneous flap based on the Descending Branch of the Circumflex Scapular Artery which exits between Teres Major and Teres Minor muscles along the axillary border of the scapula, 2 cm. above and 2 cm. posterior to the apex of the posterior axilla. The vessel then courses directly inferior toward the iliac crest. Flaps centered on this vessel may be taken as wide as 10-12 cm. and the length maybe 3-4 X the length. This flap will easily rotate to reach the coracoid process of the scapula anteriorly for axillary reconstruction following a burn contracture release. The pivot point is the exit point of the artery between the muscles. This is best determined with a Doppler. The flap can also be used to cover the shoulder. If the skin of the flap has been severely burned then the Latissimus Dorsi muscle fascia or even the lateral half of the muscle may be included in the flap. The donor site often requires grafting with a meshed STSG and a stent or bolster dressing.



Use of parascapular flap in wound that would not heal due to motion. STSG for donor site. Mobilization of skin above flap to close arm wound

<u>Latissimus Dorsi Muscle Flap</u> may be used as a myocutaneous flap or just muscle alone. If muscle alone is used, it maybe skin grafted. In chest wall reconstruction a myocutaneous Latissimus Dorsi flap is often used. The Latissimus Dorsi is supplied by the Thoracodorsal artery, a branch of the Subscapular artery. The Latissimus Dorsi is the muscle of choice when reconstructing the Biceps. It is detached both proximally and distally after the resting length has been measured. The proximal insertion is moved to the coracoid and the origin along the spine is used for the Biceps insertion, either into the stump of the Biceps or into the radial tuberosity.

<u>Cubital Artery Flap</u> is a fasciocutaneous flap taken from either side of the forearm and based at the elbow. The posterior edge of the flap is along the ulna when it is taken from either side. It can be rotated to cover the antecubital fossa or the olecranon posterior. It is based on cubital arteries from the Brachial Artery. These are small vessels and since the flap can be taken from either side, the author believes this flap may be more of a random flap but because of its location in the upper extremity, it is extremely reliable even when the length is 3X the width and reaches near the wrist. The length of the flap must be sufficient to reach the opposite side of a burn contracture release. Only if the flap is less than 6 cm. wide can it be closed. Usually the donor site is skin grafted.

Elbow contracture secondary to snake bite: cubital artery fasciocutaneous flap with step cut lengthening Biceps, fractional lengthening Brachialis and Brachioradialis

<u>Radial Forearm Flaps, antegrade and retrograde,</u> are axial flaps based on the radial artery. Both require an Allen's test to ensure that the ulnar artery can reliably provide arterial flow to the thumb and radial side of the hand. With the antegrade flap, the radial artery is ligated at the wrist and the skin island is over the distal volar forearm. Care must be taken to leave paratenon over the tendons so that a skin graft can take well. This flap is indicated for posterior elbow and olecranon coverage. It is frequently used as a microvascular flap. Remove

The retrograde flap is taken from the proximal and mid forearm and reversed to cover dorsal hand defects, especially over the dorsum and the 1st web space. The radial artery is divided proximately. Usually a vascular clip is placed on the artery proximally while the tourniquet is released. This can give further assurance of adequate collateral blood supply from the ulnar artery to the thumb before the radial artery is divided. During dissection this flap requires careful preservation of the vascular pedicles from the radial artery. A portion of radius may be taken with the flap.

These are soft pliable flaps that easily mold in to any defect. Most often the donor sites must be grafted. With the antegrade flap, care must be taken to ensure that soft tissue and/or paratenon are left intact over the flexor tendons so that a skin graft will take well. The donor site for the retrograde flap is over muscle and not a problem. In recent years it is not uncommon for both flaps to be taken as fascial and/or perforator flaps.

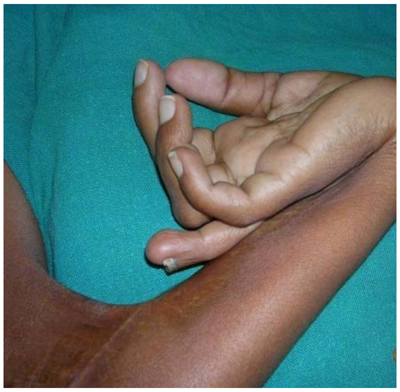
Snake bite requiring tendon transfers and reversed radial forearm flap

<u>Groin Flap</u> is a commonly used flap for hand coverage. It is a fasciocutaneous flap based on the Superficial Circumflex Iliac Artery which lies 2 cm. above the inguinal ligament and iliac crest. The long axis of the flap is along this vessel. Distal (lateral) to the Anterior Superior Iliac Spine (ASIS) the flap becomes a random flap but the author has found that the flap can be reliably taken at least 1 ½ to 2 times longer than its width past the ASIS. This flap becomes bulky past the ASIS because of the increase in subcutaneous tissue in all patients, even thin ones, and frequently the distal end needs thinning. The author starts the dissection by finding the correct plane just above the external oblique muscle and its fascia. In raising the flap proximally, there are two dangers. First, one must be aware of and protect the Lateral Femoral Cutaneous Nerve. Second, in lateral to medial elevation of the flap, the muscle fascia overlying the sartorius muscle must be taken with the flap in order to protect the blood supply to the flap which enters the flap just medial to the Sartorius. In the dissection when the sartorius is reached, a portion of the muscle fascia is included with the flap elevation. This flap can easily wrap around a hand or forearm for coverage.

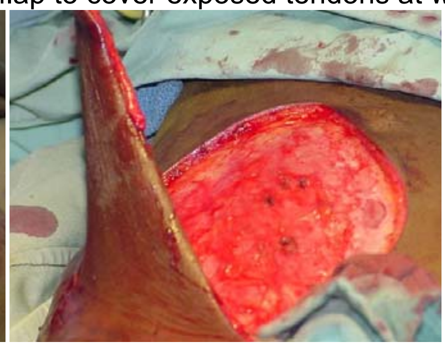
Blood supply of groin and SIEA flaps from superficial femoral artery

A Doppler can help the surgeon map out the course of the vessel and center the flap over the vessel. The donor site can almost always be closed even if the flap is 10 cm. wide. This is made possible by flexion of the hip.

<u>Superficial Inferior Epigastric Artery (SIEA) Flap</u> is a fasciocutaneous flap and is the author's flap of choice for coverage of the dorsum of the hand and wrist when the Reversed Radial Forearm Flap cannot be used. The hand with the elbow flexed lies perfectly for the flap coverage. It is based on the SIEA which arises from the Femoral Artery just inferior to the Inguinal Ligament and halfway between the ASIS and the pubic tubercle. It courses superiorly and medially toward the umbilicus and in most individuals this is a thin flap. The width of the flap can be the distance between the tubercle and spine. The length can be the entire vertical distance between the pubis and ribs. If the patient is obese, then only the superficial fascia and overlying subcutaneous tissue can be taken. This is a very reliable flap.

Snake bite with contractures: cubital artery flap used for elbow reconstruction and SIEA flap to cover exposed tendons at wrist and hand

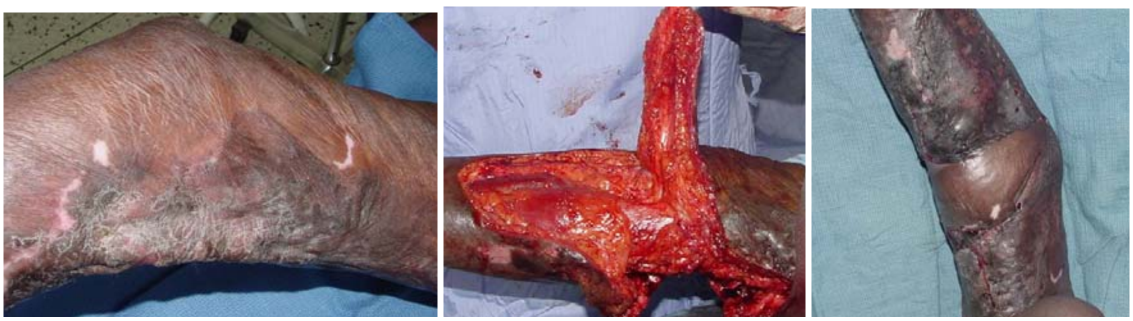
Extension contractures of MPJs after previous inadequate release and skin graft. After adequate release and pinning of MPJs in flexion, SIEA flap used for reconstruction. Pins are placed through metacarpal head and then brought out through finger tips with MPJs flexed

Tensor Fascia Lata (TFL) Flap is a thin musculocutaneous flap with the Tensor Fascia Muscle proximally and the fascia lata distally.   In orthopaedic surgery, this flap has little use except to cover the groin following contracture release and the greater trochanter. In severe untreated burns of the groin, the hip is flexed to relieve pain and a hip flexion contracture may develop. Often these contractures can be released and reconstructed without the need for a regional flap. With large defects the TFL may be needed. In unusual situations where the groin flap and SIEA flap are not adequate, the TFL flap may be used to cover hand and forearm wounds. It can be used even if the skin in the flap has been burned.   The blood supply is from the lateral femoral circumflex artery, a branch of the profunda or deep femoral artery and the pedicle enters the muscle approximately 10 cm. distal to the ASIS. This flap is a Type I axial muscle flap as the arterial supply courses the entire length of the flap. The length of the flap can be 3 X the width or to within 10 cm. of the knee. If the width is less than 8 cm. the donor site may be closed. One can take fascia lata only. The central axis of the flap is along a line from the ASIS to the lateral condyle of the tibia. The flap can be raised easily and quickly once the correct plane under the TFL is found distally. (See Burn Reconstruction chapter)

Saphenous Flap and Cross Leg Flap is a thin fasciocutaneous flap supplied by the small saphenous artery which runs alongside the saphenous vein on the medial side of the leg.   This flap is an excellent flap for coverage of the popliteal fossa after a contracture release.   Its anterior border is along the medial edge of the tibia and it can be taken posteriorly for 8-10 cm. As in other fasciocutaneous flaps, the length can be taken approximately 3 X the width. The axis of rotation is at the level of the knee joint. Flaps less than 6 cm. wide can be closed but most of the time the donor site is closed with a meshed skin graft.

This flap is also the most commonly used cross leg flap. The donor site must be grafted and a stent dressing applied (Vaseline gauze, wet cotton balls, wet and dry gauze with stent sutures tied over this dressing to hold it in place) before the flap is inset into the recipient area usually the distal third of the leg, ankle or foot. With the knees flexed, it is important to immobilize the extremities with an external fixator so that the flap is fixed into position and will not move. Any movement of the flap may disrupt the capillaries bridging the suture line. In addition, it is important to put the extremities and especially the knees through a full range of motion once the fixator is removed. There is no absolute age limit for use of the cross leg flap though the older the patient is, the more difficulty there will be in regaining full range of motion. Again final inset of the flap is best delayed for a week after division.

The cross leg flap may also include the medial head of the gastrocnemius muscle when additional coverage is required. The muscle may be used to cover one area and the fasciocutaneous portion for another area.



Saphenous flap: the muscle fascia of the medial gastrocnemius muscle can be left

Open ankle wound requiring cross leg, saphenous, flap. Note: skin graft applied before flap is inset. Final result after division of flap 4 weeks later.

Medial Gastrocnemius Flap is a Type I muscle flap supplied by the medial sural artery off the popliteal artery. It can be used to cover an exposed knee joint or the upper third of the tibia or it can be turned into the popliteal fossa. Though it can be used as a myocutaneous flap it is a bulky flap and leaves a significant donor site deformity. It is an easy flap to raise and can be lengthened by dissecting up to its origin and even carefully dividing the origin from just above the medial femoral condyle. In order to cover the entire anterior knee and distally to the middle third of the tibia, the muscle may be passed beneath the gracilis and semitendinosus tendons. If this is done, these tendons must be freed up proximally and distally to assure that there is no constricting pressure on the muscle and pedicle. Occasionally one or more of these tendons may be sacrificed without significant functional loss. The muscle fascia may also be scored longitudinally with multiple incisions through the fascia in order to gain additional width to cover the upper third of the tibia or the popliteal space. A small portion of the Achilles tendon is taken with the muscle so that the muscle flap can be securely inset into the surrounding tissue. In all reconstructions the muscle may be grafted with a meshed skin. During elevation care is taken not to injure the greater saphenous vein and saphenous nerve.

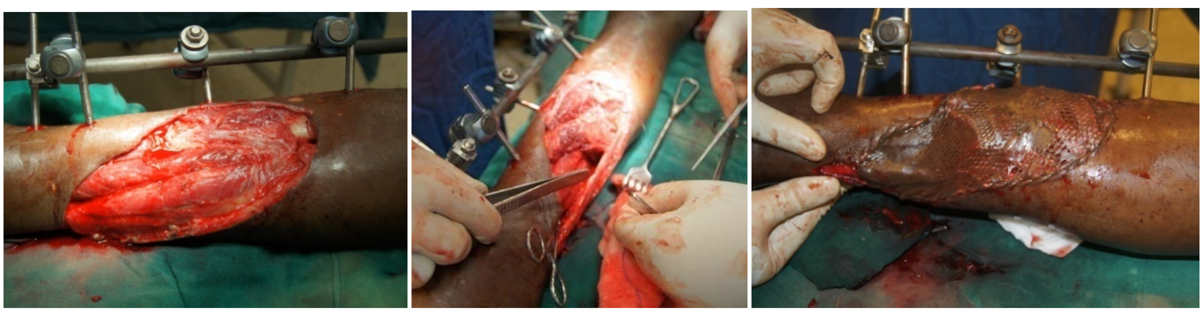
It is also possible to use the Lateral gastrocnemius muscle flap to cover lateral knee and tibial defects but because of the fibula, this muscle will not rotate to cover as much as desired. During elevation of the lateral gastrocnemius, great care is needed to protect the peroneal nerve. During elevation of both heads care is taken to preserve the sural nerve and lesser saphenous vein which lie in the midline.

Medial head of gastrocnemius muscle used to cover popliteal fossa when saphenous flap was not adequate.

Popliteal contracture with scarred skin over medial aspect of leg: medial gastrocnemius flap was used with scoring and STSG. Scar was excised in this case

Open fracture of tibial plateau. Wound débrided and medial gastrocnemius muscle flap was used to cover the wound at the time of the original surgery and fixation

Soleus Flap may be used to cover middle third tibial defects. This is a Type II muscle flap with blood supply from the posterior tibial artery for the medial half and the peroneal artery for the lateral half. The medial half of the soleus may be used, a hemi-soleus flap, or the entire muscle may be used. The author uses the entire soleus most of the time unless there is a very small defect to cover over the tibia. The soleus muscle arises from the proximal tibia and the muscle often extends to the ankle. The muscle is deep to the gastrocnemius. In elevating the distal half of the muscle, care should be taken to carefully divide and ligate the minor pedicles from the posterior tibial artery and vein. One should ligate only the pedicles needed to allow transposition of the muscle. The distal half of the soleus muscle must be dissected free from the Gastrocnemius portion of the Achilles tendon. The lateral half of the soleus can be bluntly dissected free. As with the gastrocnemius, the soleus fascia can be scored longitudinally to increase its width. The soleus has been raised as a distally based flap on the distal perforators to cover small wounds on the distal third of the leg. This flap is not reliable and the author does not recommend this distally based flap. (See Chronic Wound chapter where a soleus muscle was used acutely to cover the distal tibia in a severe lower leg injury.)



Open fracture junction of upper and middle third of tibia. Soleus muscle reconstruction with meshed STSG. Note raw appearance of muscle in middle picture: represents where muscle was sharply dissected from Achilles tendon. Reconstruction performed 3 days after injury.

Distal Third Tibial Defects

These are difficult to cover without microvascular capability. The cross leg flap can be used to cover these defects but this requires 3-4 weeks of immobilization. The sural artery flap is a very reliable flap when it is taken with the parameters described below. The use of the VAC (Vacuum Assisted Closure (Negative Pressure Therapy) is an excellent addition to the armamentarium of the orthopaedic surgeon. The VAC can be used to clean up the wound and create angiogenesis and granulation tissue over bone and tendon and prepare it for skin grafting. This technique is described in detail in the Chronic Wound chapter.

Sural Artery or Reversed Leg Flap is a reversed fasciocutaneous axial flap that may be used for coverage of the distal tibia, malleoli and heel. The classic flap based on perforators from the Peroneal Artery to the Sural Artery with the axis of rotation at least 3 fingers' breadth (5 cm.) above the lateral malleolus. The pedicle must be at least 3 cm. wide and the maximum size of the flap is 9 cm. wide by 12 cm. long. The flap cannot extend proximally more than 20 cm. from the lateral malleolus unless it is delayed. The flap is very reliable if it is raised within these parameters. Some surgeons may prefer to stage the flap elevation and inset because of the reversed blood supply. The center of the flap is the short saphenous vein. Once this vein is found proximally, the flap can be outlined. The sural nerve must be taken with the flap to ensure viability. The flap is taken deep to the muscle fascia of the Gastrocnemius but care is taken to preserve the paratenon over the Achilles tendon. In situations where the lateral side of the ankle is injured when one is unsure about the zone of injury, one can take a wider flap based on perforators from both the peroneal and posterior tibial arteries and delay the flap (see below).

Postop view of reverse sural artery flap harvested as described above to cover posterior ankle wound. Superior edge of donor site is 22 cm. above lateral malleolus but flap was delayed once to allow radical débridement of two week old wound

Chronic distal third wound—12 days old: wound débrided three times while a longer and twice delayed reverse posterior leg flap was taken based mainly on posterior tibial artery because of the injury on the lateral side of the distal leg.

Dorsalis Pedis and Medial Plantar Flaps

These are small fasciocutaneous flaps of the foot. The Dorsalis Pedis Flap is based on the Dorsalis Pedis Artery, the terminal branch of the Anterior Tibial Artery. The flap can be taken from the anterior surface of the foot and it extends down to the MPJ level. This flap can be used to cover small foot defects and the medial and lateral malleolus. When harvesting the flap care must be taken to leave paratenon over the extensor tendons so that a skin graft will take.

Wound over medial malleolus: débrided, dorsalis pedis flap raised and inset. STSG

The Medial Plantar Flap is taken from the instep of the sole of the foot and is supplied by the medial plantar artery, a branch of the posterior tibial artery. This vessel travels beneath the abductor hallucis tendon to supply the sole of the foot. The flap may be rotated to cover the heel with an axis of rotation at the medial malleolus. Terminal branches of the posterior tibial nerve may be taken with the flap to give a sensate heel reconstruction. The main advantage of the medial plantar flap over other types of reconstruction and especially skin grafts is that it provides "like" tissue to cover the heel. The donor area, the instep of the foot, is a non-weight bearing portion of the foot and may be reconstructed with a skin graft. The foot needs to be immobilized and elevated in the postoperative period and weight bearing is not allowed for 3 weeks.

Wound of the plantar weight bearing surface. Radially débrided and innervated medial plantar flap raised and rotated to cover defect with a skin graft for donor site
(Note—size of pictures changed to make all equal size)

Medial plantar flap used to reconstruct the heel after excision of malignant melanoma
An innervated flap was used

Summary:

Flaps provide an excellent reconstruction of some difficult areas. There are many more flaps than listed here. These are the most commonly used extremity flaps. Knowledge of vascular anatomy is most important for successful elevation of a flap. Temporary immobilization and elevation of the extremity is important after any flap. In addition, the wounds should be dressed so that inspection of the flap may be carried out frequently during the first 24 hours. If there is a question of viability in the first 24 hours, the patient should be returned to the operating room. Frequently the flap can be salvaged if a problem is corrected early.

(One may contact the author if you have questions at llcartermd@gmail.com)

Hand Infections

Nicola Kläeber, MD

Hand Infections

Introduction	Infections of the hand are common in the daily grind of a surgeon. If hand infections are not treated in an efficient and appropriate way, they can result in severe disabilities, like stiffness, loss of strength, loss of tissue (skin, tendons, neurovascular structures and even bone), contracture and amputation. An expedient and proper surgical intervention and the correct use of antibiotics are essential for the outcome of hand infections. The following factors influence the outcome of hand infections: • The location of infection • The infecting organism • The timing of treatment • The adequacy of surgical drainage • The efficacy of antibiotics • The health status and immunocompetence of the patient **Types of infection** Cellulitis is an infection of the subcutaneous tissue. It is often diffuse and can be associated with lymphangitis. Most common microorganisms are Staphylococcus aureus or β-hemolytic Streptococcus. Lymphangitis is more common in combination with β-hemolytic Streptococcus. Necrotizing fasciitis is a serious life-threatening infection. In the beginning it can resemble cellulitis. Patients with necrotizing fasciitis need immediate surgical care. **Patient Evaluation** Ask for the thorough medical history, risk factors like immunodeficiency (HIV) and tetanus immunization status. Signs of infection in the clinical examination are warmth, edema, redness, pain, fluctuance and lymphangitis. **Principles of treatment** In case of diffuse cellulitis immobilize the region with a splint. It is useful to cool the infected region. Nonsteroidal anti-inflammatory drugs (NSAIDs) may be given. You should start with an empirical antibiotic therapy. Use a broad-spectrum antibiotic for patients who are immunocompromised. A re-evaluation after 24-48 hours is necessary. If you find an area of fluctuance, this region needs a surgical debridement. Use a tourniquet but no exsanguination. Requirements concerning the incision: • The possibility of extension in any direction • No longitudinal incisions across the flexion crease • Minimize the exposure of blood vessels, nerves and tendons Take a swab of the abscess fluid for culture, if you dispose of a bacteriological laboratory. Your hospital lab might be able to provide a gram-stain. Excise all necrotic tissue. Sometime multiple debridements are necessary. The immobilization in a cast is necessary in most cases.

Acute Paronychia

Paronychia is the most common infection of the hand. It is an infection of the soft tissue around the fingernail and caused by bacteria. The most common infecting organism is S. aureus.

Diagnosis

Clinical marks: redness, swelling, pain, possibly pus around the fingernail

Treatment

Early phase with no pus: soaks in warm solution, antibiotics, immobilization
If pus has collected (fluctuance, throbbing pain):

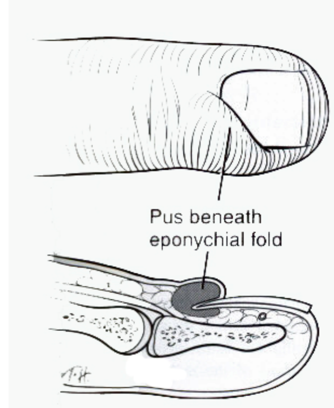
- Surgical decompression under digital block anesthesia with xylocaine (without epinephrine)
- Drainage of the abscess
- Infection below the nail requires removal of a portion of the nail
- Elevate the perionychial sulcus gently by a flat, blunt instrument
- Be careful to avoid injury of the nail bed

Postoperative Management

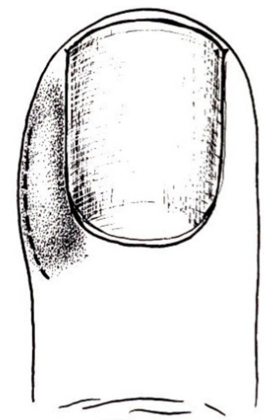
- Oral antibiotics for 7 to 10 days
- Change the dressing at least once daily
- Soaking the finger in a diluted solution of povidone-iodine (PVP-I)
- Immobilization for some days

Complications

- Rare
- Nail deformity after surgical injury of the nail matrix
- If infection not resolving within 1 week -> radiography to evaluate for osteomyelitis , swab for culture or gram-stain, repeated surgical debridement



Inflamed paronychium
© Green's operative Handsurgery



Inzision of a paronychium
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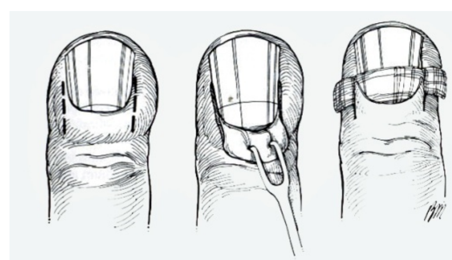
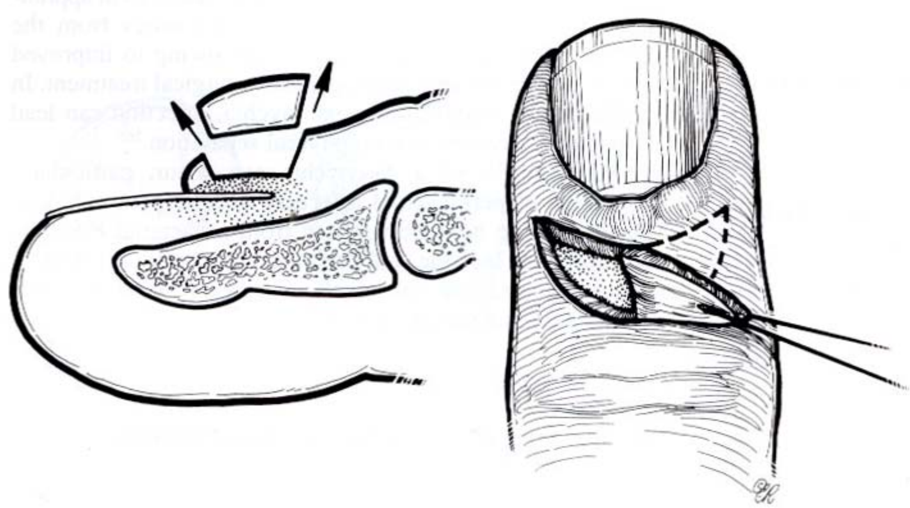


Incision of a proximal paronychium
© Green's operative Handsurgery

Chronic Paronychia	Chronic Paronychia is caused by a fungus infection. Co-organisms are gram-positive cocci, gram-negative rods and mycobacterial species. **Diagnosis** • Mild redness and swelling, mild tenderness • Contributing factors: frequent water immersion, particularly in detergents and alkali solutions **Treatment** • Conservative o Topical corticosteroids o Oral antibiotics o Oral and topical antifungal agents o Reduction or elimination of the constant exposure to moisture • Operative o Eponychial marsupalization by a 3-mm crescent of tissue beginning 1 mm proximal to the distal edge of the eponychial nail fold, the wound is left open o Nail removal when a nail deformity is present **Postoperative Management** • Remove postoperative dressing after 2 days • Daily soaking in diluted povidone-iodine solution • Wound healing by secondary intention in 3 to 4 weeks, 6 to 12 month for nail growth • Drug medication like conservative regime
	 Marsupialization © Green’s operative Handsurgery

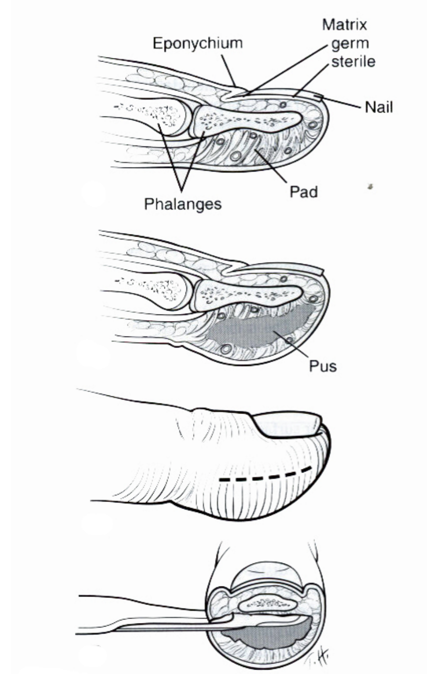
Felon

Infection and abscess in the septal compartments of the finger tip and pulp, mostly caused by S. aureus.

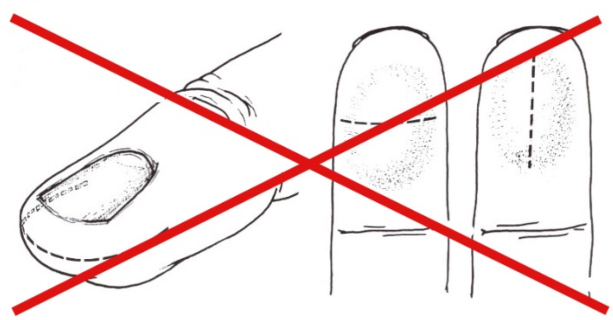
Diagnosis
- Throbbing pain, tension, swelling of the distal phalangeal pulp
- Sometimes there is a penetrating injury (wood splinter, glass sliver …)
- necrosis, osteitis, pyogenic arthritis

Treatment
Surgical drainage and antibiotics
- Digital block or general anesthesia
- Tourniquet
- Incision
    - No fish mouth incision, no Hockey Stick incision
    - Use a longitudinal incision over the point of maximal tenderness
    - Protect the digital nerves and vessels
- Keep the wound open

Postoperative Management
- First dressing change at 24 hours
- Soaking in diluted povidone-iodine solution
- Antibiotics for 5 to 7 days
- Immobilization for the first days, than early finger range of motion



Anatomy and Incision for drainage of felon
© Green's operative Handsurgery



No volar drainage because of scars in zone of sensibility
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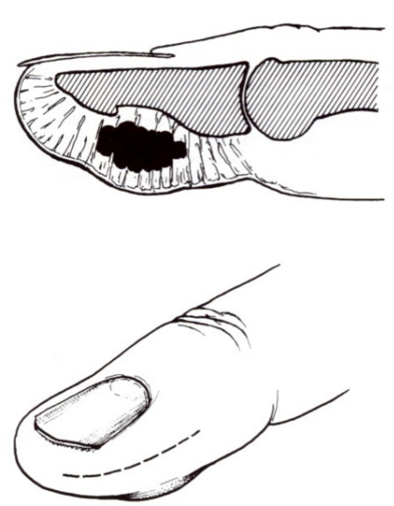

Correct incision of a felon
© Rieger, Brug; Das Panaritium; Hans Marseille Verlag

Pyogenic Flexor Tenosynovitis

Closed-space infection of the flexor tendon sheath of the fingers or thumb caused by S. aureus and ß-hemolytic Streptococcus. Pasteurella multocida is found in wounds caused by animal bites.

Diagnosis

- Penetrating trauma
- Semi-flexed position of the finger
- Pain on palpation along the flexor tendon sheath
- Pain on passive extension
- Fusiform swelling

Treatment

- In very early cases a conservative therapy with antibiotics and immobilization can be tried
- If clinical symptoms are not improving in the first 12 at least 24 hours -> surgical treatment
- Obtain material for culture or gram stain before you begin with antibiotic therapy
- Diagonal incision (Bruner incision)
- Remove all infected tissue
- Open the tendon sheet proximal to the A1 pulley and distal
- Insert a polyethylene catheter with holes cut along its length well into the sheet
- Irrigate of the tendon with about 500 ml saline until clear fluid is seen
- Adapt the skin with few stitches
- Alternative: Implantation of a gentamycin-PMMA-chain
- If necessary, remove necrotic tissue, use a larger incision and keep the pulleys!

Postoperative Management

- Dressing change twice a day
- Soaking in a diluted solution of povidone-

Clinical signs of pyogenic flexor tenosynovitis
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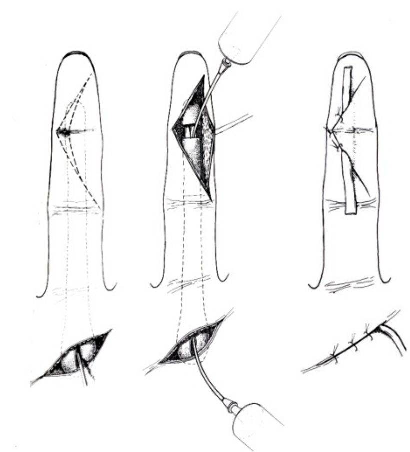

Sheat irrigation
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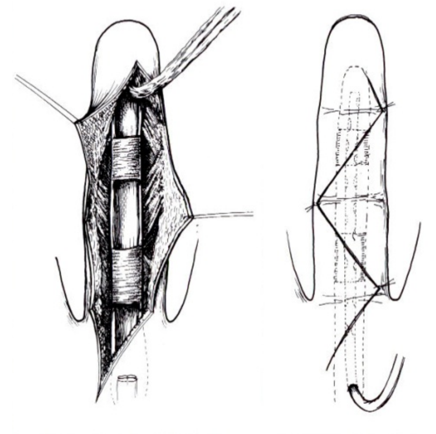
	iodine • Intravenous antibiotics • If clinical signs are not resolving within 24 to 48 hours, repeat irrigation and debridement • Early range of motion after a short time of immobilization **Complications** • Delayed surgical treatment • Inadequate decompression • Injury of the digital neurovascular structures • Limited range of motion in up to 20% of patients	 Removing of necrotic tissue © Rieger, Brug; Das Panaritium; Hans Marseille Verlag

Deep Space Infections

There are septated spaces between muscle fascial planes. They can become infected, even from a small puncture wound. We can define the **thenar, midpalmar and hypothenar space** and the area between the bases of fingers (**Collar-Button Abscess**)

Diagnosis

- Thenar space infections are most common, midpalmar space infections are uncommon, hypothenar space infections are rare
- They are mostly caused by a penetrating injury
- Swelling, exquisite tenderness, pain
- Thenar space infection: wide abduction of the thumb, difficulty with opposition
- Midpalmar space infections: loss of palmar concavity
- Collar-button abscesses: abduction of adjacent fingers

Treatment

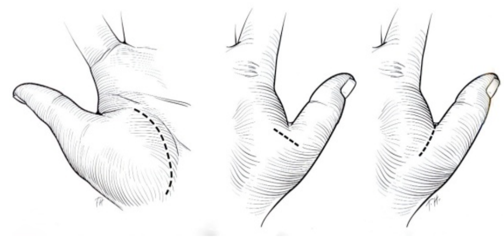
- There is no way of conservative management
- Thenar space infections and collar-button abscesses need 2 incisions
- Careful dissection
- Irrigation and debridement
- Take a swab for culture or gram-stain, than intravenous antibiotic therapy with staphylococcal coverage
- Keep the incisions open

Postoperative Management

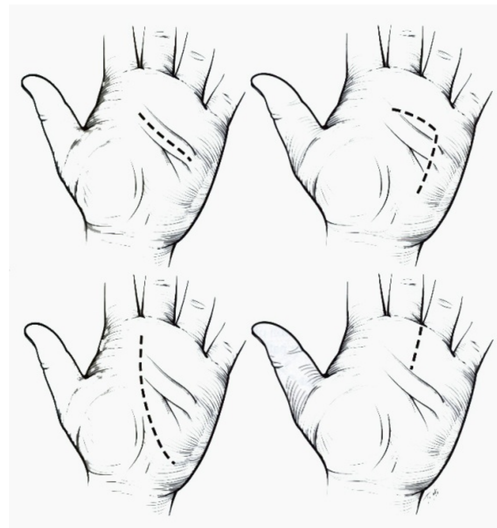
- First dressing change after 12 hours
- Soaks in diluted solution of povidone-iodine
- Pain management
- Intravenous antibiotics
- If clinical signs are not resolving within 48 hours, repeat irrigation and debridement
- Early range of motion after a short time of immobilization

Complications

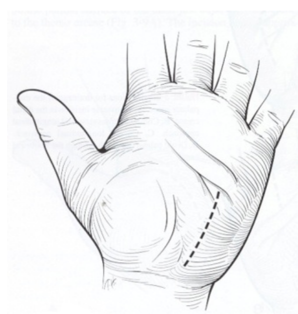
- Delayed surgical treatment
- Injury of digital neurovascular structures



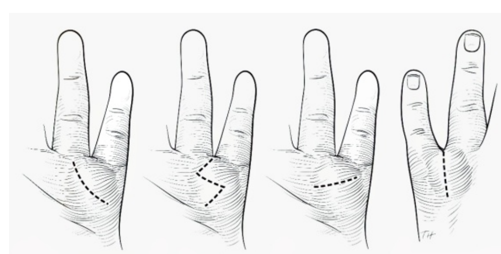
Incisions for drainage of the thenar space



Incision for drainage of the midpalmar space



Incision for drainage of the hypothenar space



Incisions for drainage a collar-button abscess

Septic Arthritis

A septic arthritis is the bacterial infection of a joint. The Joint can be destroyed by the bacteria eroding the cartilage surface of the joint in only a few days.

Diagnosis

- Penetrating trauma (bites, splinters, thorns, hooks, needles …)
- Source of injury is important for selecting empirical antibiotic therapy
- Swelling, redness, warmth, pain, fluctuance around the affected joint
- Active and passive motion -> pain
- Systemic symptoms (fever, chills, tachycardia, malaise, sweats, rash) in case of hematogenous seeding
- Laboratory evaluation: WBC, CRP ; blood cultures in case of systemic symptoms
- Radiography

Treatment

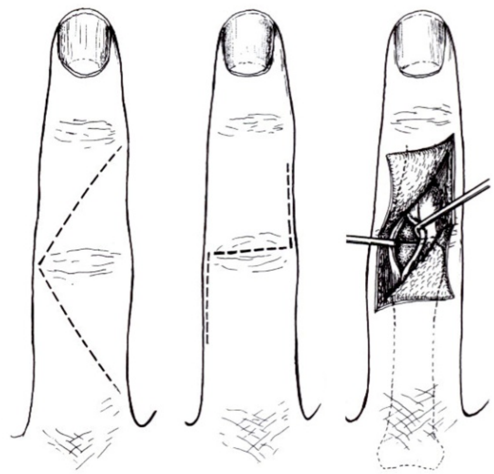
- Surgical emergency!
- Surgical drainage: Incision with arthro-tomy
- Irrigation and debridement
- Joint capsule is left open or closed over a drain
- Few loosely placed sutures

Postoperative Management

- Dressing changes twice a day, prevent encrustation of the wound
- Soak the affected hand in a diluted solution of povidone-iodine, move the joint during soaking, in the intervals immobilization
- If the clinical signs don’t resolve, repeat the surgical irrigation and debridement
- Intravenous antibiotics, switch to oral drugs after some days and clinical improvement, continue the oral antibiotic therapy for 4 to 6 weeks
- Amputation may be necessary if an infection cannot be controlled

Complications

- Stiffness of the joint
- Joint arthritis and ankylosis
- Tendon adhesions
- Osteomyelitis



Dorsal incision of PIP in case of septic arthritis

Septic arthritis of the wrist – incision

<table>
<tr>
<td>Osteomyelitis</td>
<td>
Infection of the bone

Diagnosis

Can be caused by penetrating trauma, crush injuries, contiguous spread from adjacent soft tissue infections, hematogenous seeding, postsurgical setting (pin track infections after Kirschner-wires)
Often polymicrobial infections and enteric organisms
Clinical signs: redness, swelling, warmth, tenderness
Occasionally systemic signs (hematogenous osteomyelitis or children)
Laboratory: increase of WBC and CRP
Radiography: metaphyseal rarefaction, osteopenia, osteosclerosis, periosteal reaction –> late signs
MRI

Treatment

Surgical and medical treatment
Debridement of necrotic soft tissue and necrotic bone
Wounds are left open
Plan the reconstruction if the infection is controlled
<u>Pin track infections</u>:

Can often be managed with oral antibiotics and local wound and pin care
If the infection cannot be controlled – remove the pins!

In case of fracture use a external fixator
Prolonged intravenous antibiotic therapy for 4 to 6 weeks

Complications

Are common
Pain stiffness
Deformity
Fracture nonunion or malunion
Chronic osteomyelitis
Amputation

</td>
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Osteomyelitis after operation of an enchondroma

Osteolytic lesion in X-ray
</td>
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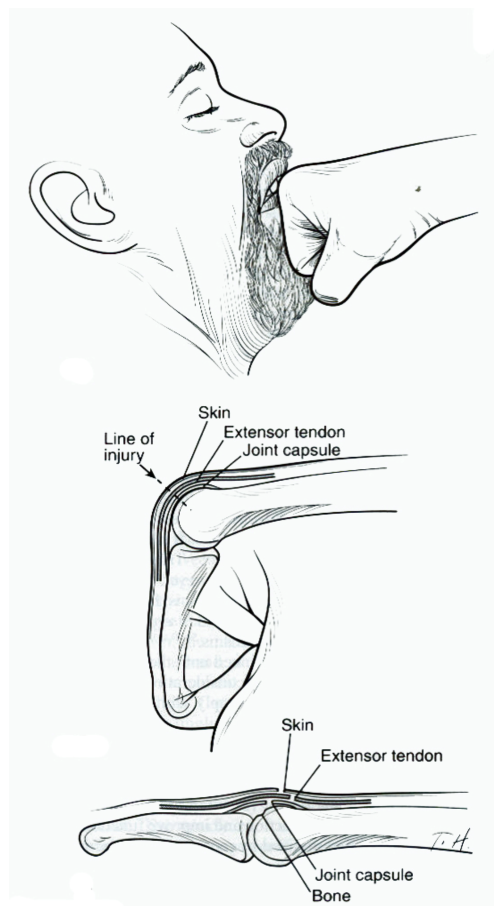
</table>

Animal Bites	• Infections caused by S. aureus, Streptococcus viridians, Bacteroides and Pasteurella multocida • Irrigation and debridement • Wounds should be left open • Update of tetanus immunization if necessary • Check for rabies (present in your region? aggressive or strange animal behavior?), if suspicious start rabies immunization • Immobilization • Antibiotics

Human Bites	• Most common areas are the third and fourth metacarpal heads of the dominant hand • The position of the fingers at the time of impact affects the location of injury to the deeper structures (tendon, joint) • Irrigation and debridement • Carefully look for injuries of deeper structures • No primary repair of tendon • Remove loose fragments of articular cartilage • Antibiotic therapy should cover Eikenella corrodens (most common bacteria in human bites), Staphylococcus and Streptococcus species • Immobilization for the time of infection • Daily soaking and dressing changes	 © Green’s operative Handsurgery

Infections associated with HIV	• Clinical presentation of infection is similar to patients without HIV, but clinical course is more severe • Most common is the soft tissue abscess • Often no self-limited course of herpetic viral infections with superinfections • Oral or intravenous antiviral therapy is necessary • Pyogenic infections need a early and aggressive surgical debridement

Diabetic hand infections	• Mostly caused by S. aureus • Broad-spectrum antibiotics and surgical debridement • Wounds should be left open • High rate of amputation
Herpetic Whitlow	• Viral infection • Often misdiagnosed as paronychia • Incubation period between 2 and 14 days • Usually involves a single finger, mostly the index finger and the thumb • In the beginning the patient has intense throbbing and pain • The pain in the beginning is disproportionately severe to the clinical findings • Erythema, mild swelling followed by small clear vesicles • In next days vesicles creep together and coalesce, may be a large confluent bulla • Over next 7 to 10 days these symptoms subside • Clinical course is generally self-limited and resolves over a 3-week period • Infectious over the whole period • No surgical treatment! • Dry dressing or a topical antiviral medication • Sometimes bacterial superinfections • 20 % recurrence

Necrotizing soft tissue infections and gas gangrene	• Rapidly advancing necrotizing infection affecting the skin, subcutaneous tissue and fascia • Swollen erythematous area of exquisite tenderness • Beyond the area of erythema the skin may have an orange-peel appearance • In the following the skin changes the color changes from red to blue-gray • Occasionally radiographs can demonstrate gas in the soft tissue • Systemic signs of sepsis develop rapidly • Rapid and extensive surgical debridement (mortality correlated to delayed surgery) • Wounds should be left open • Re-examination of the wound after 24 hours • Gas gangrene is uncommon at the hand but possible • S. aureus group A or polymicrobial, C. perfringens • Surgical emergency!

Cutaneous anthrax infection	• Bacillus anthracis • Transmitted through contaminated soil, animals or animal products • A small, painless, red macule -> papule -> becomes vesicular -> 1 to 5 cm diameter brown or black eschar • Antibiotic therapy for 60 fays • No debridement of skin lesions, they heal spontaneously

Conclusion	• Every infection with pus: incision, debridement and irrigation • Surgery + antibiotics are essential • Delayed or insufficient surgical intervention can result in severe complications and residual damages • An infection of the hand is a surgical emergency!

Further reading	6. Green's operative Handsurgery; Elsevier Churchill Livingstone; ISBN 0-443-06626-4 7. Rieger, Brug; Das Panaritium; Hans Marseille Verlag München; ISBN 3-88616-050-5 8. Resnick D et al.; Osteomyelitis and septic arthritis of the hand following human bites; Skeletal Radiol (1985) 14:263-266 9. Schaller HE; Infekte der Hand; Trauma Berufskrankh 2008:10(Suppl1):146-150 10. Fluegel M, Hankiss J; Primary Pyogenic Infections of the Hand: Anatomy, Pathology and Therapy; Eur. Surg. 2003; 35:137-142 11. http://assh.org/Public/HandConditions/Pages/HandInfections.aspx 12. HandchirMikrochirPlastChir; 2009:41:255-314

Chronic Wound Care

Louis L. Carter, MD

Chronic wounds are a significant problem in most hospitals with long periods of hospitalization, many hours of nursing care and a financial burden not only to the hospital but also for the patient. Many of these are initiated by extremity trauma, often trivial. It is important that we do not contribute to the number of chronic wounds with inadequate treatment of the acute wounds we encounter. In this chapter we will first review the care of acute wounds so that these will not become chronic wounds.

This discussion will be based on lower extremity wounds resulting from trauma but it can apply to any wound. Lower extremity wounds do not heal as well due to decreased blood supply and lack of underlying muscle in the distal third of the leg, ankle and foot. Additional factors are dependency, repeated trauma, advanced age, arteriosclerosis, venous stasis and diabetes.

Closure of these wounds can be classified as:

- Primary—closed at time of injury—may even be by skin graft or flap
- Clean closed wound concept—closed at time of injury with repair of tendons, nerves, etc. several days later
- Delayed primary—closed within the first 7 days, usually within 2-3 days, and heals as well as a primary closure
- Secondary closure—when a chronic wound is sharply débrided and closed directly or by skin graft or flap as in a primary closure
- Secondary Intention healing: wound allowed to granulate and gradually close–this is NOT ACCEPTABLE, except in rare situations, as this leads to a chronic wound

Timing of closure depends on time of injury, mechanism of injury, location, contamination, etc. Attempt should be made to close the wound immediately or at least prior to the 7th day post injury. Otherwise it will become a chronic wound. Primary closure should be our goal after initial débridement and irrigation. If an acute wound is too contaminated for primary closure on the day of injury, then further débridement and irrigation should be carried out on Day 2, Day 4, and Day 6 with a plan to close as soon as it is clean. A delayed primary closure should be carried out as soon as the wound is clean and anytime before Day 7. If a wound with minimal tissue loss is not closed early, it will become increasingly more difficult to advance the edges for closure. On the other hand, if after débridement the wound is clean but the wound is too large to close, a skin graft can be applied acutely. There is no reason to wait for granulation tissue to apply a skin graft or even to advance a flap. A meshed graft is ideal in this situation as it allows drainage and fits better into wound crevices. If less than one cm. of bone or tendon is exposed, a graft can be placed over these structures in an acute situation with an excellent chance for bridging epithelialization. If the wound is clean but with large areas of exposed tendon and bone and the wound cannot be closed primarily, then a flap should be performed before 7 days. There is no need to wait until there is granulation for flap coverage!

Débridement and irrigation is performed on every acute wound. For simple wounds of the face and upper extremity, this may be simply irrigation with normal saline as one prepares the wound for closure. If normal saline is not available, even sterile water can be used. Débridement involves the removal of devascularized tissue and foreign bodies. The amount of devascularized tissue depends on the nature of the injury as a sharp or a crushing injury, where the injury occurred as on a farm or highway or at home, and location on the body as the arm or the leg. High velocity road traffic accidents with large wounds and open fractures will need considerable débridement. If available, pulse lavage is an excellent method for irrigation as well as débridement in these wounds. Saline or Ringers Lactate should be used in pulse lavage. The need for further débridement is determined by the condition of the wound after the initial débridement. Often in lower extremity wounds one cannot be certain if all devitalized tissue has been removed and another débridement should be scheduled in 2 days. Muscle that bleeds may not be viable; on the other hand, if it contracts it is usually viable. Bleeding edges of bone indicate viability. Unless there is severe arterial bleeding that must be controlled, one should not use a tourniquet during these early débridements or one should release the tourniquet before one has finished in order to identify and débride non-bleeding tissue. Ideally, wounds should be kept moist and the extremity elevated between débridements. Allowing tissues to dry out or desiccate between débridements and dressing changes is detrimental to the tissues. Antibiotics are not used in the simple clean wounds but may be used in severe contaminated wounds. Usually a cephalosporin is chosen but for severely contaminated road or farm wounds, better gram negative and anaerobic coverage should be used. Elevation of an extremity is often forgotten but it is very important.

When closure is delayed beyond 7 days, the wound begins to heal with secondary intention and soon becomes infected and colonized with greater than 10^5 (100,000) microorganisms per gram of tissue—a special quantitative test carried out on a biopsy of 1 gram of tissue. (The definition of wound infection or colonization is a wound with greater than 10^5 microorganisms per gram of tissue.) This colonization is seen after a wound is left open or exposed for 7 and certainly after 10 days. Intermittent extensive débridements, where the entire surface is excised down to normal tissue, may prolong the development of colonization in a wound, but often débridements are scheduled as the last case of the day and are performed by junior staff. When "more important" cases take longer In small hospitals with limited operating rooms, these débridements may easily be postponed until the next day—again the last case and again by junior staff. These delays lead to a chronic colonized wound. After 7-10 days a wound will need a complete débridement with complete excision of the wound and wound edges prior to secondary closure with a STSG or flap closure.

Chronic lower extremity wound surrounded by poorly vascularized tissue. Radially débrided twice with reversed sural artery flap closure

Waiting for granulation to cover bone or tendon will result in an infected wound and will require a long hospital stays with many dressing changes and with considerable cost to the hospital and patient for the necessary supplies. More than likely the patient will not be able to pay for his prolonged care. Outpatient treatment of such wounds is unsatisfactory with lack of proper wound care by OPD/PT staff, missed days due to weekends and lack of patient compliance and dependency of extremity while coming to the hospital each day. Soaking of the wound in a whirlpool-type bath leads to cross-contamination of the wound.

Clean Closed Wound Concept:

One important concept is the Clean Closed Wound Concept. If a wound requires tendon or nerve repair but there is no one available to do this at the time of injury and presentation to the hospital, a clean wound may be loosely closed after initial debridement. A delayed repair of the vital structures may be carried out the next day or several days later. The wound can be opened for the repair of these structures and it is still clean. This is especially helpful in upper extremity surgery.

Chronic wounds:

Chronic wounds present to the hospital because:

1. Delay in presentation to the hospital

Delayed presentation is a major cause of chronic wounds

2. Delay in adequate débridement and primary closure by inexperienced staff

Delay in adequate débridement by inexperienced staff

3. Exposed bone with inadequate closure prior to 7-10 days post injury
4. Transferred patient from other health facilities
5. Problems with healing due to age, Diabetes, HIV/AIDS, failure to thrive
6. Venous stasis
7. Other causes of chronic wounds as:
    - Underlying osteomyelitis
    - Buruli Ulcer—TB
    - Marjolin's ulcer—squamous cell carcinoma
    - Necrotizing fasciitis

Why closed wounds break down and become chronic wounds:

1. Lack of proper débridement--infection
2. Lack of immobilization and splinting

3. Early ambulation and lack of elevation
4. Tension on wound
5. Early removal of sutures—remember extremity and back sutures should remain for 14 days.

Initial workup of chronic wounds:

1. Rule out causes of delayed wound healing
    a. HIV/AIDS
    b. Diabetes
    c. Tobacco/alcohol use
    d. Infection
    e. Malnutrition/anemia
    f. Edema/venous stasis
    g. Environment—dry
    h. Repeated trauma
    i. Leprosy




HIV/AIDS Malnutrition Leprosy

2. Rule out retained foreign body or fragments of bone—x-rays
3. Blood tests for HIV, DM and especially Hct/Hgb
4. Culture and Sensitivity if available
5. Biopsy to rule out Marjolin's Ulcer (SCC) if wound present for 10 or more years
6. Arterial pressure: Ankle/Brachial index to rule out decreased oxygen delivery to lower extremity (Less than 0.9 is abnormal)

Often, a chronic wound results from <u>neglect</u>; however, if adequate care has been given, then the other contributing causes should be searched for.

<u>Treatment methods</u>:

There are three possible methods for the treatment of chronic wounds when first seen:

First, one can dress the wound daily with intermittent débridements with the hope that the wound will go on to secondary healing with epithelialization or finally granulate and be ready for a skin graft. As mentioned, this method requires significant nursing care and is costly for the patient.

Chronic wounds with incomplete debridement and infected granulation tissue
These wounds will not heal without further extensive débridement

This method is commonly used but not recommended, but healing will be improved if the wound can be kept moist at all times. It is not easy to keep a wound moist, but it will accelerate wound healing. One possible method is to dress wound with a bulky gauze dressing once daily, place extremity on a Macintosh (rubberised fabric), and drip saline on the dressing every 1-2 hours. This requires dedicated nursing care.

Unfortunately, allowing the wound to granulate with minimal intervention is a commonly accepted practice. These wounds are often managed by junior staff members and aggressive débridements are not performed on a regular basis. The resulting granulation tissue is infected and must be sharply removed prior to skin grafting. Even so, this granulation tissue is often heaped up and not an ideal recipient surface for a skin graft. Often the débridement is only through the superficial granulation tissue and the graft will take but will be prone to breakdown with minor trauma, especially if the graft overlies the anterior tibia or other bones. (Note: superficial granulation tissue will always bleed but it still infected) On the other hand, if sharp tangential débridement of granulation tissue is carried down to bleeding dermis or subcutaneous tissue, the graft or flap will heal well.

Method of débridement for chronic wound : Use Weck blade or skin graft knife to tangentially excise chronic wound or burn down to bleeding dermis or soft tissue

Second approach is a more aggressive treatment and will lead to early wound closure. This method requires "ownership" of the wound by an experienced surgeon. An aggressive and extensive débridement is carried out when the patient is first seen. On Day 2, 4, etc. the wound is again radically débrided with a plan to close the wound as soon as it is clean, usually by 7 days and definitely by 10 days with either direct closure, skin graft or flap. The days of débridement are carefully scheduled after the initial débridement to ensure that closure will be done by Day 10 at the latest. (These days are scheduled to coincide with the surgeon's operating days.) This method decreases the hospital stay and saves everyone money. Between débridements an attempt is made to keep the extremity elevated and the wound moist throughout the day, using the method described above. Unless there is "ownership" of the wound by a senior staff surgeon, the wounds will be neglected with inadequate debridement and Day 10 will pass without wound closure.

Summary of Technique:

1. Initial wide débridement with removal of devitalized tissue and foreign bodies is carried out. Initially the surgeon should be able to predict when and how the wound can be closed: direct closure, STSG or a flap.
2. Débride every 2 days and try to close by 7-10 days post initial débridement. This will require dedication and ownership of wound by experienced team member.
3. Keep the wounds moist and the extremity elevated between débridements.

Third is a newer approach using the VAC—Vacuum Assisted Closure—or Negative Pressure Therapy. It is an excellent method for debridement and even gradual wound closure in chronic wounds. (It may also be used in acute wounds. See below.) After the initial debridement, the negative pressure suction can be applied and the dressing should be changed every 2-3 days. The supplies and suction for this are produced by KCI but home-make varieties are possible

KCI VAC products are ideal when available

VAC 1 week-note flat, clean granulation tissue

anywhere in the world. Supplies needed are: foam rubber as found in seat cushions—grey black foam is best, food wrap found in most major grocery stores in large cities around the world, small suction tubing as #12-16 nasogastric tubing, tape and a continuous suction machine that registers up to 125 mm Hg. suction. This suction removes interstitial fluid and decreases wound edema, increases blood flow and decreases tissue bacterial levels. Negative pressure therapy, 125 mm Hg., elevates the blood flow to four times the baseline value but higher pressures may inhibit blood flow. The negative suction produces angiogenesis and new granulation tissue which is flat and neither hypertrophic nor infected. After several dressing changes the wound is usually clean enough to consider closure—usually by skin grafting. If the wound is deep with multiple crevices, then 2-3 weeks of suction may be necessary. If bone or tendons are exposed a flap should be used as soon as the wound is clean.

The extremity should still be elevated with the VAC and the suction gauge should be checked several times a day. In countries where the small portable KCI suction pump can be obtained, the VAC procedure can be used on an outpatient basis. Waiting more than 3 days between dressing changes may result in a foul odor at the time of the dressing change but usually the wound is still clean with flat healthy granulations. Even in remote hospitals, usually one can get all the required supplies in their capital city once a month.

The VAC is usually changed in the theatre with minimal sedation. Further irrigation and débridement of any devitalized tissue and removal of foreign bodies should be done when the VAC dressing is changed. Use of the VAC reduces the need for dressings and manpower required for daily dressing changes.

Method of VAC application (if home-made and not commercial):

1. After the wound has been surgically débrided, the VAC is applied.
2. The foam rubber used should be approximately 3-4 cm. thick. It is usually cut into different size pieces, wrapped and sterilized prior to surgery. At surgery it is cut to the exact size of the wound.
3. The foam rubber is then placed in the wound. One may tape the foam rubber to the skin to hold it in place. A small suction catheter 12-15 Fr. or a nasogastric tube is placed on top of the rubber or threaded through the foam rubber using a long hemostat.
4. The food wrap is wrapped around the foam rubber to hold it firmly in place. It has to be wrapped well at each end to prevent the air leak. "Shrink" wrap can be used if available and it sticks to the skin the first time around. Food wrap does not stick to the skin the first time around but it sticks to itself. Ideal is a commercially produced transparent adhesive such as Op Site (Smith Nephew) or Vi Drape which sticks to the wound the first time around, but these products are often unavailable in large quantities.
5. Tape is used at each end to hold the food wrap firmly against the extremity and suction is applied to the suction tubing. Immediately the foam rubber should collapse. The tubing should be taped to the extremity to prevent accidental removal.
6. If an external fixator is in place for a fracture and the pins are close to the wound, then the food wrap must be carefully wrapped around the pins to prevent air leakage.

Home-made VAC: wound débrided, measured, foam cut (only 3 cm. thickness), placed directly on wound, suction catheter as NG tube laid on or passed through foam, wrapped with food wrap and connected to suction at 125 mm Hg. pressure

7. The suction should have a meter which can be regulated to nearly 125 mm. Hg suction pressure. This has been shown the ideal pressure. If the foam rubber does not collapse when the suction is turned on, then there is not an air tight seal at the wound, connections are loose or the suction is not working properly. The suction machine should be dedicated for this patient only and not used for other patients with different demands.

8. The dressing is changed completely every 2-3 days. Usually in 1-2 weeks the wound is ready for grafting or a flap. When the VAC is used, granulation tissue will develop over bones and tendons and a skin graft or flap can be used to complete closure.

VAC can be used <u>acutely</u> after initial débridement. Repeat débridements at each VAC change. Home-made VAC was used for three weeks before STSG. A soleus muscle flap was used to cover exposed tibia at the initial débridement.

When wounds fail to respond to this aggressive therapy, then one must look closely for further for other causes of chronic wounds as HIV/AIDS, sickle cell anemia, underlying osteomyelitis, TB or Buruli Ulcer, malnutrition or anemia.

Summary

Aggressive treatment by experienced staff of chronic wounds will not only save the patient many days of hospitalization but will also greatly reduce the cost to both the patient and hospital. The care of these wounds may not be initially appealing to the senior staff; however, early ownership of these wounds will result in a number of complex reconstructions for the surgeon and will bring great satisfaction for both the patient and surgeon with the final result and early discharge home.

Reconstruction of the Burned Extremity

Louis L. Carter, MD

Preface

In many countries, an extremity problem or deformity is sent to the orthopaedic service initially for evaluation. Burns over joints frequently lead to contractures if untreated or if treatment is delayed. Joint contractures are disabling with inability to use the hand and upper extremity or difficulty in walking. Since joints are involved, these burn contractures are included in this here.

Etiology of Burn contractures:

Why do burns lead to joint contractures? If a full thickness burn (Third Degree) over a joint is not treated properly with early debridement, skin grafting and proper splinting it will heal by secondary intention with contraction, scar formation and gradual epithelialization from the wound edges. The myofibroblasts in the healing wound lead to contraction in the wound and a joint contracture will develop. Wounds and burns are painful when the joint is extended; therefore, during the healing process the patient holds the joint in flexion to reduce the pain. This leads to further contraction. The contracture may be linear with normal skin on both sides, but more often it involves a larger surface area.

Partial thickness burns have dermis remaining and heal without the need for grafts or splints. If a deep partial thickness burn (second degree burn) in child or older adult becomes infected, then the burn will quickly convert to a full thickness burn and is prone to develop a contracture if over a joint and if left untreated. Children and older adults have very thin dermis. The readers of this chapter will not usually see or treat early burns, but it is important that you understand the prevention of contractures which are so disabling.

Prevention of burn contractures:

Often the patient does not come to the hospital until there is a contracture. If a patient with a full-thickness burn over a joint seeks early care and the joint is grafted and splinted until the burn heals, then a contracture will be less likely. Wearing a splint for weeks and maybe even months can be painful and will require understanding and compliance. Most full thickness burns over a joint will lead to contracture if left untreated. Partial thickness (Second Degree Burns) will often heal without contraction and splinting is not necessary; however, daily wound care is very important to prevent infection. If the patient does come to the hospital during the healing process and before a rigid contracture develops, then the joints should be splinted in the following positions, also known as *positions of protection*:

- Axilla—hold in abduction by hanging the arm to an IV pole or bed or splinting. Splints are difficult to wear and compliance is often poor. The so called “airplane splint” is cumbersome and not well tolerated.
- Elbow—splint in extension
- Wrist—neutral or slightly extended (may develop extension as well as flexion contracture according to location of the burn)
- MP Joints—hold in 80-90° of flexion
- IP Joints—hold in extension
- Hip—in neutral
- Knee—in extension

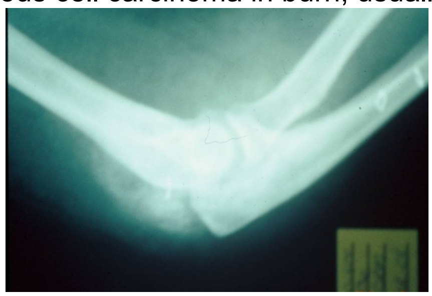
- Ankle—in neutral

The splint should be worn until the wound is mature and well healed. This will differ according to site, patient age, understanding and compliance, and many other factors.

<u>Differential Diagnosis</u>

Joint contractures are not always caused by burns. One must be aware of the other causes:

Snake Bites—often a deeper injury.
Heterotopic Bone Formation (HO)—need x-rays; especially common at elbow and often without a deep burn or even a burn at the elbow
Trauma around joint with bone and/or joint injury
Septic arthritis with scarring of joint capsule
Pterygium—congenital flexion contracture at either elbow or popliteal fossa
Marjolin's Ulcer—squamous cell carcinoma in burn, usually >10 years old

Heterotopic Bone (HO)

Marjolin's ulcer

<u>History and Physical</u>

The patient should be questioned concerning previous injuries, infections, depth of initial burn (HO may occur after minor burns), snake bites, etc.

On physical exam one must confirm that the burn is likely the cause of the contracture. With a septic joint or trauma there may be scarring across a joint but no evidence of a widespread burn. Often a pterygium has been explored even though there is no evidence of a burn. These congenital contractures cannot be released since the neurovascular bundle lies immediately beneath the skin.

Though the treatment may be the similar for some of these, the contractures due to snake bites and trauma may involve much more than just the skin and subcutaneous tissues.   It is important to recognize this preoperatively.

<u>Presentation:</u>

Usually one will see the burn contracture after the burn has healed by secondary intention. If the contracture is in the developmental stage and a wound is still present, then a decision will need to be made whether or not to release the contracture or wait until the wound is completely healed. This determination will be made based on a number of factors including whether or not the wound is infected, how close it is to complete epithelialization, will the patient return for follow-up, etc.   If the burn is in the early stages of healing then a contracture release should be carefully performed.   If it is almost healed, then waiting until complete healing with epithelialization and maturation of the wound would be best.   On the other hand, some contractures will never epithelialize completely due to recurring trauma. This is often seen in the axilla or popliteal fossa since the patient continues to use the arm or attempts to walk.

These wounds continually break down with use of the extremity and fail to heal. In such cases if the wound is otherwise mature, it is best to cover the patient with antibiotics and go ahead with the contracture release.

Maturation of the burn scar usually takes six to twelve months after complete epithelialization. Before six months the skin is thin, immature and poorly vascularized. Though a release may be done at this time, the immature and fragile skin surrounding the release will often breakdown and fail to heal without further grafting.

Special situations: early contracture, healed but immature skin, axilla fails to heal

Sub acute burn contracture Released early with STSG

Healed but immature skin: breakdown when contracture released

Never heals: cover with antibiotics and release

Types of Reconstruction:

In the plastic surgery literature from Europe and North America, there are a number of sophisticated techniques shown for burn reconstruction. In many parts of the world the burns are much more severe and these techniques do not work well. There is a reconstructive ladder for burn contracture surgery just as with other wounds. This ladder does not apply to acute burns where skin grafting and splinting is adequate or to scarred areas which are not over joints. This ladder applies to joint contractures and is opposite the ladder for basic wound closure as it begins with flaps and not simple closure or skin grafts.

Flaps offer the best reconstruction after the contracture has been released.
Flaps of any type may be used but fasciocutaneous flaps are the best both functionally and aesthetically. These flaps consist of the skin and the superficial fascia. The superficial fascia is the thin fascia superficial to the muscle fascia. It is the same as Scarpa's fascia in the abdomen. Vessels lie above this superficial fascia just as the superficial inferior epigastric artery and vein lie above Scarpa's fascia in the abdomen. (When one does an open hernia repair, there is bleeding from these vessels just before one divides Scarpa's fascia.) These vessels supply the skin and are the reason long fasciocutaneous flaps survive. When the superficial fascia is included in a flap, then the blood supply to the skin of the flap is included in the flap. The

thickness and ease of identification of this fascia varies according to age and area of the body. These flaps are usually thin and mold into a defect well. Y-V advancement flaps and Z-plasties are often considered just random skin flaps but if the superficial fascia is taken with these small flaps, then they are more reliable even though they are not axial flaps. Scarred tissue should not be included in these small flaps.

Axial fasciocutaneous flaps are flaps where one or more known vessels transverse the entire length of the flap and the flap length may be 3-4 X its width. An axial pedicle flap is considerably more reliable than a random flap which is supplied by multiple unnamed vessels Flaps can also contain underlying muscle fascia or muscle. Myocutaneous flaps, also axial flaps, contain skin and muscle but tend to be bulky and are rarely used in burn reconstruction. Muscle only flaps may be used on occasion and a skin graft can then be placed over the muscle. Muscle flaps do not rotate as well as fasciocutaneous flaps because of the extra bulk.

Flaps are better than skin grafts for several reasons. Flaps carry their blood supply and are more reliable. Flaps are soft and pliable and provide excellent contour and cosmesis. Another very important reason is that flaps do not require post-op compliance on the part of the patient or family. With the joint covered by the flap, splinting is only required for 7-10 days while the wound heals. Long term splinting and compliance is not required as the contracture will not recur.

Skin grafts are used when the tissue around the defect is of poor quality and inadequate for a flap, the blood supply to the planned flap has been compromised due to a previous injury, the defect is too large for any regional flap, and a distant flap cannot be used. Full thickness skin grafts (FTSG) are better than split thickness skin grafts (STSG) and the STSG sheet grafts are better than meshed grafts. Grafts with more dermis (as a FTSG or thick STSG) give a better functional result with increased durability and elasticity. There is also better cosmesis with a FTSG. One caveat with the thicker grafts is a decrease in “graft-take,” so it is best to put the thicker grafts where the blood supply is better like the upper extremity or especially the hand and fingers. In contrast to flaps, skin grafts over a released joint require long term splinting, not only for complete healing but more important to prevent recurrent contracture. Long term splinting requires patient and family compliance, not only in wearing the splint continuously but also in returning for follow-up. A patient with a flap reconstruction will often get a good result even if the patient never returns for follow-up after discharge. Muscle flaps with a STSG do well as the area of contracture release is filled with muscle. One must splint these until the STSG has taken well.

All skin grafts contract but the thinner the graft, with less dermis, the more contraction one can expect. In addition, the thinner the graft, the less pleasing will be the aesthetic result. FTSG over the finger joints do well. In dark skinned individuals, all grafts including FTSG will be darker than the surrounding skin. This is especially noticeable on the light palm of dark-skinned patients. Patients should be told about this before surgery.

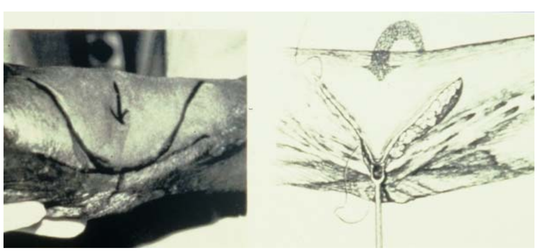
FTSG are usually taken from the groin where large grafts are available and the donor site closed in the inguinal crease. One may take grafts as large as 15-18 cm. in length and 6-10 cm. wide (height) from the groin. Other sites for FTSGs are the antecubital fossa, the wrist crease, hypothenar eminence and abdomen.

Planning the contracture release and reconstruction:

If contracture is a simple web with normal skin on either side of the web and the contracture is less than 60 degrees then one or more Z-plasties may be performed. This is a rare situation in many parts of the world as the burns are more extensive without a discrete, linear web. Z-plasties require wide undermining of all surrounding tissue and not only the limbs. If the surrounding skin has been burned, then the limbs of a Z-plasty will not rotate well even with wide undermining. A skin graft may be necessary in the center of the release with the possibility of a recurrent contracture.

Z-plasties attempted in contracture greater than 60°
with scarred skin. Did not work and skin graft required

If there is burned skin on one side of the contracture but the other side of contains normal skin, then a Y-V plasty may be done but only if the contracture is less than 60 degrees. This is often seen in burns of the axilla and elbow. The limb of the Y is the incision through the scar, whereas the V portion of the Y is the good non-burned skin that advances into the defect. If the contracture is slightly more than 60 degrees, a back-cut along the inside base of the V may allow minimal additional advancement of the flap, but with a contracture > 60° a regional rotation flap or distant flap will be best. The author has found this amount of contracture, an angle greater than 60°, a fairly reliable indication for a regional flap.



Elbow Y-V plasty with good skin on
one side and <60° contracture

Elbow contracture with >60° contracture
Cubital artery fasciocutaneous flap reconstruction

If there is burned, scarred skin across the entire joint, then a regional flap should be performed if possible. If there is extensive burned skin in the proposed flap donor area and neither a local, regional or distant flap can be used, then skin grafting must be done. This will require prolonged splinting.

Method of Contracture Release:

The release of the contracture over major joints is perpendicular to the longitudinal axis in order to lengthen it, unless a Z-plasty or Y-V plasty is planned. With any contracture, both normal skin as well as the burned and scarred skin are contracted and must be released. A transverse release across the joint from mid-axis on one side to mid-axis on the other side is necessary even if normal skin is divided—unless this normal skin will be used in a planned flap reconstruction. In this case, the complete release will be gained when the flap is elevated. The incision is down to the dermis and no deeper. After the initial superficial incision the blade is gently pushed through the scar while the assistant passively extends the extremity or joint. This will prevent damage to important deep structures. Once normal subcutaneous tissue is reached, the scalpel is no longer used and the joint is passively extended until full release of the contracture is reached. If full extension cannot be reached then the surgeon must be sure the release is from mid-axis to mid-axis across the joint. As stated, a transverse release over the mid-joint and from mid-axis on one side to mid-axis on the other side is necessary even if one divides normal skin with the scar tissue. Though some surgeons remove the scar tissue, this is not always necessary and will not alone return the extremity to full length since unburned tissues are also contracted. If there is severe hypertrophic scarring or keloid formation, these scars may be removed with improved cosmesis but these abnormal scars may still recur. Once the release is carried out, any scarred skin left behind will no longer lie directly over the joint line and will not lead to further contracture. If a Z-plasty or Y-V plasty is used for a simple web contracture with less than a 60° contracture, mid-axis to mid-axis release is not necessary.

Once the contracture is released the bleeding must be controlled. Just before the tourniquet is released after large contracture releases, the author places gauze sponges soaked in a dilute adrenaline solution on the wound. This solution is made by mixing 2-3 cc. of 1/1000 adrenaline in 100 cc saline. A capped sterile needle is placed in the solution to identify it. In large wounds, several hundred cc. of saline may be necessary. This solution may also be used to control the bleeding from skin graft donor sites. In small releases as in fingers, some leave the tourniquet up until after the reconstruction has been completed and the wound has been dressed with a pressure dressing.

Occasionally one will encounter a deeper contracture from previous injuries, septic arthritis or snake bites. It is important to recognize these contractures prior to surgery. With careful examination, it is obvious that the scars or burns are not extensive and that deeper scarring must be present. Any burn that leads to severe contracture will often be an obvious wide-spread burn, unless HO is present. Post trauma or snake bite injuries may be more localized but deep. In these cases one may have to lengthen tendons by Z-plasty (step-cut incisions), fractional lengthening and even release the joint capsule in order to extend the joint—this is often seen at the elbow. The limiting factor that will prevent full release is a tether on the blood vessels and/or nerves. One must always be aware of tension on vessels and nerves and frequently check distal pulses as the joint is released and extended. If a pulse if lost, then the joint must be flexed until a pulse is felt or heard with a Doppler. The reconstruction should be carried out in this position. Serial casting and lengthening may then be carried out slowly at weekly intervals until the extremity is straight. A Doppler is ideal for monitoring the pulses during these phases. This serial lengthening is easier when there has been flap reconstruction.

What if a joint cannot be completely released or if after release and reconstruction, there is lag or incomplete extension? Fortunately, in some joints as the axilla and elbow, full extension and range of motion is not required for adequate function and activities of daily living. On the other hand, full extension of the hips and knees is important in order to walk. An ankle near 90° is also important. Usually with full soft tissue release, capsulotomy if necessary, and serial lengthening, a functional position can be reached. Shortening of one bone and/or an arthrodesis is the last resort.

Dressing and splinting and postoperative care:

If a flap has been used for reconstruction, a bulky dressing is used. If skin grafts are required for the recipient area or donor area, a Vaseline or Xeroform dressing is applied, then cotton balls soaked in saline is used to hold the graft down especially in the crevices. Wet gauze is placed over the cotton and followed with dry gauze dressing. Wet dressings promote healing. Splinting and postop care will be described for each area. Antibiotics, usually a Cephalosporin, are given preop in all contracture releases. Whether or not the antibiotics are continued in the postoperative period is a decision for the surgeon to make. If deep crevices were found that could not be prepped well before surgery, antibiotics may be continued several days. In patients with diabetes and other co-existing illnesses, antibiotics may also be given for a longer period of time.

Planning a flap reconstruction:

With Z-plasty and Y-V flaps blood supply is usually random. If the superficial fascia has been included these flaps should survive. Regional axial flaps include the parascapular flap in the axilla, cubital artery flap at the elbow, radial forearm for dorsum of wrist, groin or superficial epigastric flaps for the wrist or hand, etc. One should measure the width of the defect created after the release and then mark out the flap. It is most important that the rotated flap reach the mid-axial line on the opposite side of the release. So "measure twice and then cut once." Ideally the width of the flap will equal the width of the defect following release. If this is not possible, often the skin above and below the release can be undermined and mobilized for closure. If this is not possible a skin graft can be placed above and below the flap. As long as the flap lies in the center of the released joint, a skin graft can be placed above or below the flap without concern for recurrent contracture and without the need for long term splinting. It is still important to splint until the grafts have taken well. A fasciocutaneous flap can be 3X longer than its width. If the width is 6 cm. or less (this is rare) then the donor defect may likely be closed primarily, depending on the presence of surrounding scar tissue. If the donor defect cannot be closed primarily, it can always be closed with a skin graft. The end of the flap is usually tapered and often the distal end of the donor site can be partially closed.

Fasciocutaneous flaps are not always possible. When there is a widespread scarring and deep burns there may be little hope in finding good skin for a local or regional flap. Even then, the underlying muscle fascia and even muscle (see axilla) may be taken with the severely burned and scarred skin with a good result. If the there are severe hypertrophic or keloid scars that one does not wish to transfer, in some areas muscles (axilla and popliteal fossa) may be taken alone and a skin graft placed over the muscle. These reconstructions will contract very little, even with the overlying skin graft because the underlying muscle lies in the released area (see Latissimus Dorsi in axilla and gastrocnemius in popliteal fossa).

When grafting is necessary:

Flaps, though ideal, may not be available and grafts are then required. It is important to splint grafts not only until the graft has taken but also until there is complete healing and maturation of the graft and when a recurrent contracture is not likely to develop. This varies according the joint involved, the severity of the initial contracture, the age and compliance of the patient, and the thickness of the graft reconstruction. Most often splinting will be required for a minimum of 3 months and sometimes 6 months or longer. Skin grafts will be described under each joint.

Elbow contracture with surrounding burned skin
Required FTSG and prolonged splinting

Suture technique:

Flaps are best sutured in place by interrupted sutures and the author uses a Gilles' type suture technique with a monofilament absorbable suture where the ligature is in the surrounding normal skin and not in the flap. The Gilles' suture is a half buried horizontal mattress (This is just like a horizontal mattress suture but the half buried portion is horizontal through the dermis of the flap and not through the skin.) Actually any kind of suture material can be used. Occasionally, if there is any tension on the flap, a few deep sutures may be necessary. Otherwise a one layer closure is sufficient.

Skin grafts can be stapled or sutured in place with absorbable suture such as chromic. Running sutures are preferred and can be used if a few drainage holes are made in a sheet graft. If the graft is meshed, as used for donor sites, a running suture works fine. Some prefer to lay the graft on with fibrin glue when it is available. With absorbable sutures, there is no need for suture removal.

Specific Joints:

Axilla

The axis of motion of the axilla is from 0° when the arm is adducted at the side to 180° when the arm is fully abducted over the shoulder. A range of motion from 0° to 135° allows for most activities of daily living, most jobs and for personal hygiene and care of our hair. Some may have good function but an unsightly web when abduction greater that 135°is attempted and the patient, often a female, may request corrective surgery even though function is adequate.

If a linear contracture involves the anterior or posterior axillary fold with normal skin on either side and the contracture is less than 60°, one or more Z-plasties may be performed. The angle of the Z-plasty flaps should be 45-60°. All limbs must be of equal length and wide undermining of surrounding tissue is necessary. Limbs of 45° will give 50% increase in length and 60° will give a 75% increase based on the length of the limbs. All flaps should contain superficial fascia to enhance blood supply.

Axillary contracture in young boy with mobile skin and good skin on either side of contracture. Band excised with Z-plasty reconstruction (markings are for a parascapular flap which was initially planned)

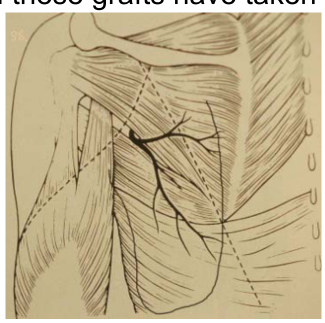
If there is scarring on one side but not the other side of the contracture in either the anterior or posterior fold—usually the scarring is anterior on the chest or posterior on the back with normal skin in the center of the axilla—a Y-V plasty is an excellent reconstruction. Again the contracture should be <u>less than 60°.</u> The limb of the Y is through the scar and the V portion is in the advancement flap in the normal central axillary skin. Actually the V is best incised like a U to give the best possible blood supply to the tip of the advancement flap. Care should be taken in dissecting out the advancement flap to keep the superficial fascia in the flap. In contractures of the anterior axillary fold the release should extend up to the coracoid process of the scapula. This will be the mid-axial point of the anterior axilla. It is important to make the V portion long enough to reach. This is done by undermining the entire flap and all surrounding tissue must also be released, not just the flap. If the flap has been raised but will not reach the tip of the release, then limbs should be extended or a back-cut may be made at the base of one limb of the V. This may give an extra 1-2 cm. of advancement.

Axillary contracture with burned chest wall skin but good central axillary skin. Y-V advancement performed. Note good skin in axilla. Scarred skin does not require removal as patient has excellent function postop. Long term splinting is not necessary.

For posterior axillary fold contractures, the incision can be carried up to an imaginary point for the mid-axis. The V advancement flap is taken from the central axilla as in the anterior fold contracture.

For these contractures, books will often describe many other complex Z-plasties and W-plasties. In the significantly scarred axilla, the author has found the techniques described above reliable. With scar tissue on either side of the contracture, multiple small flaps do not advance as one would like or as some textbooks suggest. Also these local flaps in burned skin will often not survive and there will be tip necrosis, possibly requiring further débridement and even grafting with necessary long term splinting for a good result. This creates a problem when there is poor patient compliance and follow-up.

If there is scarring in most or all of the axilla, then a parascapular flap must be used. This is an axial fasciocutaneous flap supplied by the descending branch of the Circumflex Scapular Artery and should be long enough to reach the coracoid process anteriorly. This vessel can be found and traced with a Doppler and point of rotation of the flap is where the vessel exits between the Teres Major and Minor muscles. This is found by identifying where the posterior apex of the axilla is and measuring 2 fingerbreadths superiorly and 2 medially (toward the spine). The flap length can be 3 to 4 x the width of the flap or up to 30 cm. long. The center of the flap is an imaginary line straight down inferiorly toward the iliac crest from the exit of the vessel. The medial portion of the flap overlies the scapula. If the flap skin is deeply burned and scarred and viability is questioned, it can still be used. The muscle fascia of the Latissimus Dorsi or even the anterior half of the muscle can be taken with the flap. In young people this muscle is relatively thin and not bulky. In the rare case where there is very thick scarring with keloids, then all or a portion of the muscle can be used and a STSG placed over it. The axilla <u>should never</u> be reconstructed with just a skin graft alone. Contraction will always reoccur due to gravity and the difficulty in maintaining abduction of the axilla with splinting, especially after discharge. Closure of the donor area depends not only on the width of the flap taken but also on the quality of the skin in the flap donor site. If the donor area is only 6-8 cm. wide, then it may be closed primarily. If the flap is greater than 8 cm. wide or if there is significant scarring in the area, then the donor site must be grafted. A skin graft at the donor site is away from the axilla and will not lead to recurrent contracture. In some cases of severe axillary contracture, the flap, no matter how wide, will not cover the recipient area in the axilla and skin grafts must be placed above on the arm and below on the chest. Again, these grafts are not over the joint and recurrence will not occur even if the grafts are meshed; however, one should not discharge the patient until these grafts have taken well—maybe up to two weeks.

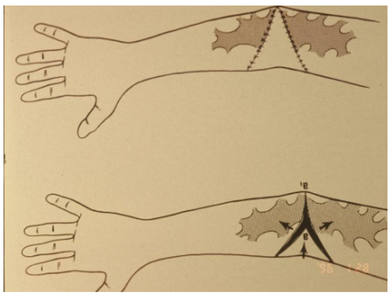



Axillary contracture with deep back burn: Parascapular flap with lateral half of Latissimus Dorsi muscle. Tip of flap inserted at coracoid process and STSG above and below flap. Y-V plasty used for reconstruction on right side

Postop a bulky dressing is applied in the axilla and the arm is elevated to an IV pole for 7-10 days. Skin grafts should be dressed with Vaseline gauze, wet cotton balls, wet and then dry gauze and a stent or bolster dressing. At ten days, unless there are some large skin grafted areas in the donor site or around the recipient area that have not healed completely, the patient can use the arm normally without the need for a splint. Some children may still have pain at the skin grafted sites and may need elevation for an additional week.

Elbow

The same techniques are used for the elbow contractures. Z-plasties or Y-V advancement will work if the contracture is less than 60°. As in the axilla, one or more Z-plasties may be used if there is good skin on either side of a linear web contracture. A Y-V plasty can be used when there is burned skin on one side of the contracture and normal skin in the antecubital fossa. A back-cut may used to gain 1-2 cm. but one must be careful since an extensive back-cut may divide needed blood supply.



Y-V reconstruction elbow

Elbow contracture: Y-V plasty with back-cut
When extended preop, contracture was slightly >60°

The flap of choice for a contracture greater than 60° is a cubital artery fasciocutaneous flap from one side of the forearm in an unscarred or minimally burned area. In the author's experience, this flap can be taken from either side of the forearm with the length up to 3X the width. The donor site may need grafting if the width is greater than 6 cm. If all the skin in the cubital fossa and forearm is severely scarred and flap rotation difficult, then skin grafting maybe necessary. Full-thickness grafts are best but thick STSG may be used with prolonged splinting for at least 12 weeks to prevent recurrence. Other more complex flaps for the elbow include a proximally based radial forearm flap, distally based lateral arm flap and a pedicle flap from abdomen. The proximally based radial forearm flap may also be used to cover the olecranon.



Snake bite with >90% contracture: Long antecubital artery fasciocutaneous flap reconstruction with step-cut lengthening of Biceps and STSG donor site
Note: muscle fascia remains with muscle and is not part of flap

<u>Heterotopic Ossification</u> (HO)

HO must be ruled out with any unusual elbow contracture and especially in burns where the elbow is not burned or minimally burned. HO can occur in the elbow with distant burns. X-rays need to be taken to rule out HO in these unusual cases. The treatment of HO is controversial. If both elbows are involved, then aggressive release of one side is usually performed early. If only one elbow is affected, then surgery is usually delayed until maturation of the HO with no further progression. If there is also a skin contracture, this will be treated appropriately after the HO is removed. The HO is usually removed through a medial mid-axial approach with ulnar nerve decompression and transposition.

Wrist: both dorsal extension and volar flexion contractures occur.

Flexion Contracture of Wrist

In long standing flexion contractures, full volar release with near normal range of motion may not be possible without division or lengthening of flexor tendons. <u>This is avoided if possible</u>. If after transverse release of skin and scar from mid-axis to mid-axis, the wrist cannot be extended to at least neutral, then a proximal row carpectomy with a dorsal approach may be necessary. A skin graft, usually a FTSG, is used to reconstruct the volar side after release. The wrist should be splinted or pinned for at least 3 months to limit recurrence. A nighttime splint should be used an additional 3 months. Any residual flexion deformity at the wrist will limit function. Every effort should be made not to expose the tendons with the volar release. Flexion contractures at the wrist may be associated with MPJ extension contractures in a Z deformity pattern.

Burn contracture with wrist, MPJs and PIPJs in a Z deformity pattern: required volar wrist release and proximal row carpectomy, capsulotomies of MPJs, passive stretching of PIPJs with pinning, excision of scarred dorsal skin, and skin grafts for the volar wrist and dorsal hand

Extension contractures at the wrist may occur if the burns are dorsal and these may be severe with the back of the hand adherent to the forearm. Care must be taken to leave soft tissue and paratenon over the tendons during release. After the release, severely scarred skin may be excised for improved cosmesis. In most cases split thickness skin grafting—sheet grafts are better than meshed grafts-- and splinting for 3 months is sufficient. Occasionally after release where the burns have been very deep, tendons may be exposed. In these cases, a flap will be necessary, with a distally based radial forearm, a groin flap or superficial inferior epigastric flap. These contractures may be associated with MPJ flexion contractures. (See Flap chapter)

Severe extension contracture wrist: careful release with preservation of soft tissue and paratenon allowed for STSG reconstruction. Splinting of wrist for minimum of 3 months

Once the wrist contracture is released, any <u>MPJ contractures</u> should be addressed at same time. Often MPJ extension contractures may be passively corrected in children and pinned in position of function—MPJ in 80-90° flexion. In long standing contractures this will not be possible. MPJ extension contractures may be due to the severe scarring on the dorsum of hand. In such cases, not only should the MPJs be released from mid-axis to mid-axis (all four ulnar digits and thumb are often involved) but significant scar tissue on the dorsum of the hand should also be removed, not only to allow MPJ flexion but to improve cosmesis. If extension contractures remain, then capsulotomies must be carried out in the following sequence: first release of dorsal joint capsule, then collateral ligaments, then accessory collateral ligaments and then free the volar plate. These are done sequentially and from one side to the other as necessary until the joint is released. All structures may not need to be released. Release until the MPJs can be placed in 80-90° flexion. Attempt is made to preserve the soft tissue over tendons and bone by carefully dissecting down to the joint on one side of each joint. The ligaments on both sides of the joint may be released through one incision along the extensor tendon. In unusual cases the MPJ contracture is > 90° and following release the metacarpal head is exposed and the extensor tendons subluxed to one side. In such this situation a flap will be required. Rarely the extensor tendons may need to be lengthened, best in distal forearm, to prevent subluxation. In this situation the MPJs need pinning for 6-8 weeks. The flap of choice is either a distally based radial forearm flap if the proximal volar forearm skin is preserved or most likely a Superficial Inferior Epigastric flap which covers the dorsum of the hand well. (See Flap chapter)

Severe MPJ extension contractures: release with mid-axis to mid-axis incision, care to preserve soft tissue and paratenon over tendons, open capsulotomies of MPJs with release of dorsal capsule and collateral ligaments, and pins through MPJ and brought out through finger tips. Dorsal skin was not excised in this case.

In this Zigzag contracture pattern, if the wrist is flexed and the MPJ extended, then the PIPJ will often be flexed. These PIPJ flexion contractures are discussed below.

Deep burn dorsum of hand from road traffic accident

Reverse radial forearm reconstruction

Flexion contractures of the MPJs often involve all four fingers. Again, it is very important to release from mid-axis on the radial side of the index to the ulnar side of the small. Normal appearing skin in a long-standing contracture will require release. It is important to first incise the skin and then push with the scalpel so one does not injure vessels, nerves and tendons. Ideally a FTSG is used for reconstruction but if not available a thick STSG is used. It is important to mold the wet cotton balls into the crevices, apply a bulky gauze dressing, and then splint or pin the MPJ in extension for at least three weeks and then at night time for three additional weeks.

Flexion Contractures at PIPJ and DIPJ:

One should check for co-existing syndactyly with PIPJ contractures as it is best to release both at the same operation. PIPJ contractures also require mid-axis to mid-axis release with care not to injure neurovascular structures. Passive extension while the scalpel is pushed through the scar is important. Once the subcutaneous tissue is reached, any remaining contracture is released through passive extension. If full extension cannot be gained, then one must be certain one has divided the skin from mid-axis on each side. In very rare situations, the check rein ligaments and collateral ligaments may need to be released to gain full extension. Full-thickness grafts are used. The PIPJs may be pinned with K-wires. In children hypodermic needles (18 to 21 gauge) are used as they are cheaper and more likely available in large quantities. At one time the author tied stent or bolster dressings over the cotton ball dressings, but now the fingers are just dressed with a wet cotton balls, wet and then dry gauze and splinted in extension for 2-4 weeks according to the severity of the contracture. If, in spite of careful release, the flexor tendon sheath is opened and the tendons exposed, grafting can still be done.

PIPJ contractures: released mid-axis to mid-axis, FTSG and pins for 2-3 weeks. Note: previous incomplete release of Index PIPJ. Previous scar was not excised. Grafts will be darker forever

FTSGs over the finger joints usually do well. In dark skinned individuals, all grafts including FTSG will be darker than the surrounding skin. This is especially noticeable on the light palm of dark-skinned patients. If only one or two fingers are released then the final result may be improved by taking a FTSG from the palm (distal wrist area), hypothenar eminence or the instep of the foot—but this is rarely done.

Burn Syndactyly:

There are numerous flaps for congenital syndactyly. In burn syndactyly, the skin is scarred and not pliable, therefore an hour-glass flap has been found to fit into the defect best. It is important to advance the dorsal flap volarly to the level of the normal web space. The thickness of this flap at the level of the extensor tendon paratenon—leaving the paratenon on the tendon. If fingers are badly burned and normal landmarks are difficult to identify, the web space is half the distance between the distal palmar crease and the PIPJ crease. FTSGs are used where necessary.

Hour-glass release of Syndactyly: Important that dorsal flap reaches web space on volar side
In this release there are no zigzag incisions as in congenital syndactyly—just straight line
1-at PIPJ, 2-at MPJ, 3-halfway between 1 and 2, 4-halfway between 2 and 3, 5-halfway between 3 and 4 and narrow point in web, 6-halfway between 1 and 3, end of flap, 7-width of distal end of flap, from midline to midline on adjacent fingers

First Web Space Contracture with Thumb Adduction:

The following techniques have been used:

Z-plasty
Four flap plasty—ideal if skin is pliable
Index finger flap
Dorsal hand transposition flap
Reverse radial forearm flap
Groin flap
FTSG/thick STSG—requires pinning for 6-12 weeks

A flap reconstruction is best. As in the contractures discussed above, the type of reconstruction depends on the availability of good quality skin for transfer. In long standing tight adduction contractures, the Adductor Pollicis must be released at its insertion at base of proximal phalanx. It may then be recessed and sutured back to the metacarpal proximally to maintain some adduction of the thumb. If most of the surrounding skin is badly scarred, a reverse radial forearm flap gives an excellent reconstruction. Below are the extremes of reconstruction: Four flap Z-plasty and radial forearm flap

Four flap Z-plasty is ideal when good pliable skin available

Severe burn contracture of first web space: Release of Adductor Pollicis (AdP) from proximal phalanx, recessing the muscle back to metacarpal, and reverse radial forearm flap

Lower Extremity--Groin

These contractures may be flexion and/or adduction contractures. Every previously described technique may be used according to the extent of the contracture and the quality of skin remaining. In severe cases Tensor Fascia Latae flaps may be required. STSGs will usually be needed for the donor area and possibly above and below the flap. Splinting the extremities in extension and abduction can be carried out by bilateral Buck's traction and later with a spica cast if necessary. If skin grafts have been used in the release, then splinting may be needed for 3 months or longer.

Release and Tensor Fascia Latae (TFL) flap reconstruction
No splinting or compliance required postop

Severe burn contracture with hip flexion deformity bilateral and umbilicus at pubis: Release and TFL flaps over hip joints and skin graft above joints on abdominal wall and over donor areas. Kept in hospital until skin grafts healed and no splinting was necessary

Knee

Popliteal contractures are common and disabling. Skin grafts do not do well as the primary method of reconstruction. If absolutely necessary, they can be used with long term—six months—splints or casts. On exam it often appears that Z-plasties and Y-V plasties will work and occasionally they will in minimal contractures with good skin: however, in the author's experience, these local flaps do not work well in the popliteal fossa. The Saphenous flap, a fasciocutaneous flap from the medial side of the leg, is an ideal flap to use if the skin of the medial leg is unburned. It is very important to extend the release to the mid-axial line on the lateral side of the knee and the flap must reach this point. The axis of rotation of this flap is at the joint line. If the medial leg skin is badly burned, then a Medial Gastrocnemius flap can be used. The fascia over the gastrocnemius is scored several times longitudinally to increase its width when it is rotated into the defect. A skin graft covers the muscle. The leg is kept in extension until the grafts are well healed.

Severe flexion contracture knee: Long saphenous flap to reach mid-axis on lateral side and skin grafts where needed but joint is covered with the flap

With contractures of the popliteal area, other causes of contractures as joint injuries must be ruled out. Occasionally step cut lengthening of the posterior tendons, Hamstring tendons, and release of the posterior joint capsule may be necessary. If the distal pulse is lost when the leg is extended, then the reconstruction should be carried out and followed with serial lengthening over several weeks.

Missed diagnosis: Not burn but secondary to septic arthritis. Reconstructed with medial gastrocnemius muscle flap, STSG and serial lengthening over two weeks. Same can be done for severe popliteal fossa burn when medial leg skin severely burned.

Ankle

Most often there is a dorsiflexion contracture of the ankle. Occasionally one or more Z-plasties are possible if there is good skin on either side of the web. Most reconstructions at the ankle require skin grafting. During release, an attempt is made to not expose the extensor tendons. The long extensor tendons may be sacrificed if necessary since the Extensor Digitorum Brevis tendons will extend the toes. A tight Anterior Tibialis tendon frequently limits complete release. If possible a step-cut lengthening is carried out above and below the release. The tendon is exposed proximally and distally where there is overlying soft tissue. The tendon is divided on opposite sides above and below and the foot is passively flexed. This is similar to a closed release of the Achilles. This leaves the tendon covered by its tendon sheath in the mid portion of the release and a skin graft can then be used. The ankle can be splinted in a neutral position or slight equinus. A Steinman Pin through the calcaneus and into the distal tibia is an excellent method to maintain the release long term. Ideally the ankle should be splinted for a minimum of 8 weeks and with severe contractures up to 12 weeks is best.

When contracture is very severe and the ankle release leads to joint exposure, a cross leg flap or a reverse sural artery flap maybe needed. The cross leg flap is the same as the saphenous flap. After the flap is inset over the defect, the legs are held together with an external fixator to limit motion at the recipient site. The flap is divided at 3-4 weeks and mobilization of the legs is immediately carried out while the patient is under anesthesia to prevent postoperative contractures from the long term fixation. Usually external fixation with the knees flexed is not a problem for patients under 20.

Severe dorsiflexion contracture ankle with exposed joint after release:
Cross leg (saphenous) flap, reconstruction and external fixation
for 3-4 weeks. Skin graft donor site before inset of flap

Feet and Toes:

Release, skin grafting (FTSG if available), pinning and splinting for 4 weeks is ideal. Most commonly, there is a dorsal contracture of the toes but a flexion contracture on the plantar surface is not unusual. Preoperatively, these foot contractures must be thoroughly cleansed and postoperatively these wounds must be carefully dressed and splinted and elevated until the grafts have healed well. Weight bearing is limited until the wounds are healed. Syndactyly between the toes can be treated as for the fingers; however, these are often minimal with little functional loss and no additional surgery is required.

Occasionally, there will be ankle and toe contractures with a rotational deformity of the foot. The ankle is released as described above and then the toes are released. The rotation corrected and pins are placed. A pin is placed from the calcaneus through the talus and into the distal tibia. One or more pins are placed through the toes and back into the calcaneus or talus. These pins are left in a minimum of 6 weeks with elevation of the lower extremity. No weight bearing is allowed until the pins are removed. After the pins are removed, a short leg cast is applied for 6 additional weeks and weight bearing is allowed.


Dorsal contracture with rotation of ankle joint: Note pins through calcaneus into distal tibia and pin through 5th metacarpal into hind foot to hold correction of rotation

Conclusion

Burn reconstruction is difficult and perfect results are not easy to achieve. The goal of all extremity burn reconstruction is improved function. Resection of scars, such as keloids, is done when function will be improved and not for cosmesis alone. Flaps are used when possible as they do not require long term follow-up and patient compliance. It is important to wait until the burn wounds have healed and matured in most cases before starting surgical reconstruction. This requires patience on part of the patient and the surgeon but waiting will always give the best results. It is most important that extremities are elevated until all wounds are well healed.

Low Back Pain

Robert F. Greene, MD

INTRODUCTION

Back pain is a universal problem, frequently seen in Africa. Most often it is in the lower back, but sometimes it is in the dorsal spine or the neck. It is most often associated with lifting heavy objects repeatedly or with trauma. In spite of extensive study of this common problem, the exact mechanism of the pain is still uncertain in most cases.

KINDS OF PATHOLOGY AND SOURCES OF PAIN

Arthritic – The facet joints are synovial joints which can be inflamed by osteoarthritis, Rheumatoid Arthritis, Ankylosing Spondylitis and other systemic arthritis syndromes.

Muscular – acute or chronic strain, fatigue, trauma, positional or postural strain

Disc disease—discs deteriorate with age and various degrees of usage. Heavy labor, lifting and repetitive bending may cause the discs to wear out. Rupture of the posterior disc may permit the extrusion of the nucleus pulposis into the spinal canal, pressing on the nerve roots or the spinal cord. This will result in nerve root pain and neuropathy. Compression of the cord usually causes an upper motor neuron lesion, whereas compression of exiting nerve roots causes a lower motor neuron lesion.

Tumors of the spine, benign or malignant, primary or metastatic

Fractures of the spine sometimes cause deformities which will result in abnormal stresses on the facet joints and muscles.

Osteoporosis may result in painful compression fractures with wedging and kyphosis.

Infection in or about the spine—discitis, mainly in children, or Pott's Disease (Tuberculosis of the disc and adjacent vertebrae).

Visceral sources of pain – pancreatic, renal, or uterine

Narrowed spinal canal and nerve root outlets (Spinal stenosis)—may cause lumbar "claudication," increasing pain and weakness when walking a distance.

THE SPINE

- Seven cervical, twelve thoracic and five lumbar vertebrae and muscles. The sacrum and coccyx form the base.
- Discs connect the vertebrae and are composed of the ring-shaped **annulus fibrosis** which contains in the center the **nucleus pulposis**
- Maintains erect posture and allows movement in all directions
- Protects the spinal cord and exiting nerve roots.
- Forward bending places pressure on the lumbar discs
- Rotational or twisting bending places more stress on the facet joints than on the discs
- The forward arch of the lumbar and cervical spine is called **lordosis**
- The backward hump of the thoracic spine is called **kyphosis**

CLINICAL HISTORY

Determine the onset and duration of the pain, exactly where it localizes, and whether there are neurologic symptoms. Ask about previous treatment and x-rays. Ask about occupation whether the patient has any ideas about possible causes. Ask about whether the pain radiates to the legs and which side. Ask about aggravating and relieving factors, including response to NSAIDS.

ANKYLOSING SPONDYLITIS

- An inflammatory arthritis mainly affecting the sacroiliac joints and spine
- Clinical criteria: Age <40, duration >3 months, insidious onset. morning pain and stiffness of the back, improving with exercise
- NSAIDS usually help this pain
- Gradual progression to rigid spine ("bamboo spine")
- Bilateral sacroiliitis visible on xray
- Decreased chest expansion
- Lab test: HLA-B27

TB OF SPINE (POTT'S DISEASE)

- Gradual destruction of the disc by tuberculous infection spread hematogenously.
- Infection and collapse of the anterior portion of the adjacent vertebrae results in a sharp kyphosis and palpable bump on the spine called a "gibbus."
- AP xrays often show a fusiform opacity which is the abscess next to the spine.
- The patient often presents with neurologic findings—weakness or paralysis along with back pain.

EXAMINATION

Observe the patient's demeanor and posture when he enters the examination room. Much can be learned from seeing how he sits, stands and lies down. Watch how he removes his shoes. A patient with a severe, acute low back strain will have a great deal of difficulty moving, bending over and reaching down.

Physical Examination

Sequence of back evaluation:

Position of patient	Action or test	Finding or conclusion
While standing	Walk on tip toes and heels	Dorsiflexor and plantiflexor strength (L5, S1, S2)
While standing	Forward flexion toward toes	Assess sciatic irritability
While sitting	Straight-leg-raising	Assess sciatic irritability
While sitting	Reflex testing knee Achilles	L4, S1
While sitting	Motor testing great toe ext.	L5
While sitting	Sensation testing	Dermatome localization
While lying supine	Straight-leg-raising	Assess sciatic irritability
While lying supine	Patrick test (FADIR – flexion, adduction, internal rotation)	Assess the sacro-iliac joints Assess hip joints
While lying prone	Palpate spine and muscles	Assess localization of pain, search for gibbus, kyphosis, loss of lordosis, spasm
While lying	Proceed teaching stretches	3-step home program

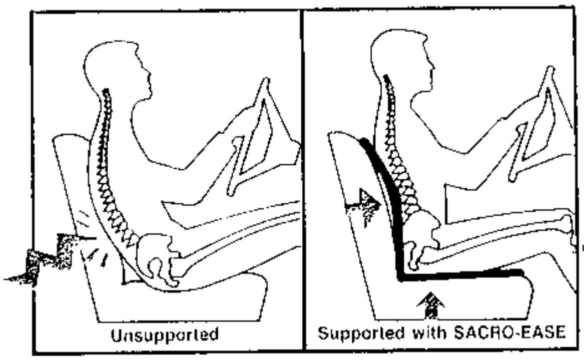
Excessive reactivity to touching may suggest psychological overlay. Compare what you found objectively to what the patient reports subjectively.

X-ray studies usually are not necessary unless a problem has been present for several weeks and even then the findings are usually negative. Often an abnormality seen in the spine is not the cause of the patient's complaint. Arthritic change in the vertebral column is normal for persons over age 50. In cases of persistent radicular pain associated with objective neurologic findings a CT scan or MRI scan should be considered. Patients should be told that surgery will not necessarily solve back pain problems.

TREATMENT - MANAGEMENT

If the problem is acute (onset in the past few days) the patient should be reassured that his symptoms have an 80% chance of clearing with rest and analgesics during the next several days. Bed rest should be intermittent through the day with alternate periods of sitting in a comfortable chair and walking. Bed rest should not be prescribed for more than 3 days or so; more bed rest is non-productive. The purpose of treatment here is to *break the vicious cycle of pain and spasm.*

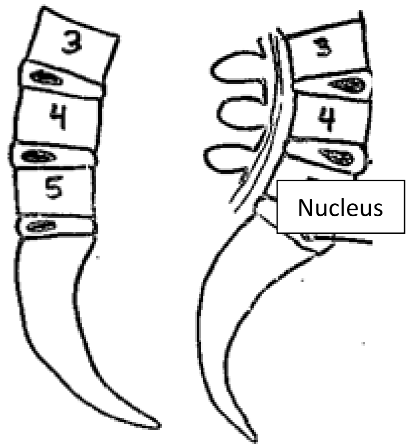
Patients should be taught that repetitive forward bending and incorrect sitting posture are the main causes of backache. Below are suggestions for sitting and bending properly and safely.
Always sit in a chair with the lower back supported with



something firm.

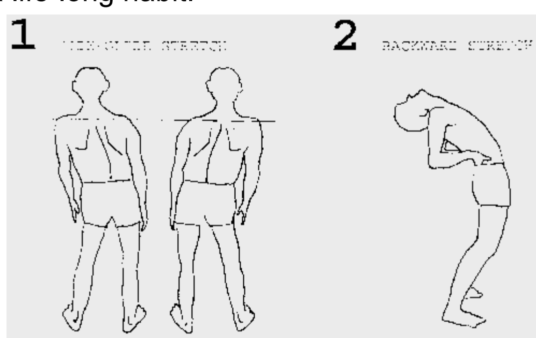
(note movement of nucleus in extension)

LUMBAR FLEXION   LUMBAR EXTENSION



Keeping the nucleus anterior is desirable since ruptures posteriorly

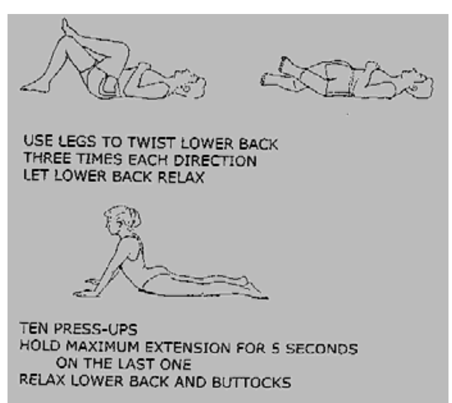
Patients with low back pain should stop bending forward the normal way and change to the twisting bend. This method will usually relief the pain of bending forward. If it is successful, it should become a life-long habit.



The pictured standing stretch exercises may be used many times a day to relieve back pain. This should be used during sports activities and after sitting for a long period of time.

These three recumbent exercises may be used every morning for a warm-up and stretch. It is a safe way to put on stockings, since the back

PUT ON SOCKS LYING DOWN



is protected in the recumbent position. This series of stretches may be done in one minute, so everyone has time to do them. These are not muscle building exercises, but stretches. Do not do the extension stretch if radicular or sciatic pain is made worse.

Epidural Steroid Injections can also be used when the usual conservative measures have not brought relief to radicular and spinal stenosis type pain. An alternative to injection may be high dose oral prednisolone tapering down over a period of 10 days.

Physical therapy consisting of massage and modalities can be very helpful. Some use alternating warm and cold applications. Elastic sacroiliac supports can be very helpful during the first week of an acute back strain. It enables the patient to be more active in walking and standing while the soft tissues heal.

Patients with chronic, recurrent back pain need to give attention to their life styles. Elderly persons need to avoid heavy lifting activity and carrying loads. Overweight patients need to lose weight.

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Amputations

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CONSIDERATIONS FOR LOWER EXTREMITY AMPUTATIONS

Introduction

A variety of indications exist for amputations about the upper and lower extremities including trauma, infection, neoplasm, and deformity. Of all the amputations performed in the United States annually, approximately 16% are related to trauma. Although this number seems modest, it turns out that nearly 50% of those living with an amputated limb had a traumatic indication. Across the specialty of orthopaedics, it seems uniform that the best predictor of a good postoperative outcome is a patient's preoperative condition with regard to overall health and baseline functional capacity. Those that find themselves the victims of high-energy trauma are typically in the younger, more active population with the greater potential for rehabilitation. Children with deformities resulting in a functionless limb may require an amputation, as the limb becomes more of a burden than an asset. In the absence of a systemic disease process, including solitary primary tumors of bone and soft tissue, patients can also enjoy an impressive capacity for recovery. Difficulties with postoperative rehabilitation are encountered when a systemic disease process accounts for the indication of the amputation, such as seen in the medically infirm population including those with cardiopulmonary disease, diabetes, peripheral vascular disease, and immunosuppressive states including human immunodeficiency virus (HIV). Smoking should probably be considered a systemic disease in its own right as it can have devastating consequences on the healing of the soft tissues after an amputation. The deleterious effects of nicotine on a patient's peripheral vascularity can compound an already compromised extremity in the setting of traumatized osseous and soft tissues and infection.

The majority of this chapter will deal with amputations of the lower extremity. Considerations with regard to upper extremity amputations will be presented towards the end of this manuscript.

Patient Factors

Important things to consider in patients necessitating an amputation include their overall health, nutritional status, and accuracy of their diagnosis. Patients should be optimized medically, specifically in their cardiopulmonary health as amputations at various levels in the lower extremities can increase the overall energy expenditure of locomotion. For example, a transtibial (below-knee) amputation has been shown to increase a patient's energy expenditure by around 30%, a transfemoral (above-knee) amputation by 70%, and a hip dysarticulation by 270%. Of note, a transmetatarsal amputation does not affect a patient's energy expenditure. In a medically frail patient, this increased requirement for efficient oxygenation of their tissues can quickly exhaust their cardiopulmonary capacity if they are not medically optimized. In the setting of diabetes, glycemic control should be tight with serial monitoring of not only glucose levels but also of monthly glycosylated hemoglobin (HbA1C) values. Measures such as an insulin pump should be considered as labile perioperative blood sugars have been shown to be an independent risk factor for postoperative deep infection in certain orthopaedic procedures. Unless an amputation is required in an urgent setting, patients should be required to stop smoking to give their residual limb every chance of mending uneventfully. Nutritional status is paramount and often overlooked in the orthopaedic population. Laboratory studies including total lymphocyte count, serum albumin and prealbumin, and serum transferrin can be used to document and monitor a patient's state of nutrition. With infection and malignancy, advanced imaging studies are often required and biopsies are crucial for an accurate tissue diagnosis. Amputations must be done through a healthy bed of tissue that is proximal to any crush injury, compromised perfusion, infection, and tumor. Traditional teaching in diabetics describes amputating through a level, particularly at the leg, with preserved transcutaneous oxygen tension. With infection, the amputated portion should be sent for cultures and with malignancy, should be sent for histologic analysis to ensure proper margins. Lastly, amputations should be approached from a multi-disciplinary perspective with involvement by the treating orthopaedist of various services including infectious disease, oncology, general medicine, vascular surgery, nutrition, therapy, and social services.

Despite the relatively healthier demographic involved in trauma-related amputations, a significant percentage of patients experience postoperative complications including rehospitalization, need for revision amputation, wound complications including superficial and deep infection, and severe disability. The goal of an amputation, regardless of the indication, is to create a painless, durable, well-padded residual limb capable of prosthetic wear. An amputation procedure should be divided into two separate parts, the elimination of the traumatized, infected, neoplastic, deformed, or dysfunctional portion of the extremity and subsequent reconstruction, with the latter presenting the most challenges to even the most experienced orthopaedic surgeon.

Basic Surgical Principles

Wound Management

Adapted from the orthopaedic trauma literature are some essential tenets to adhere to with limb amputations. The soft tissue envelope is probably the most important variable in determining the outcome of an amputated extremity. In a traumatized limb, it is imperative to perform an aggressive initial debridement after the requisite hemostasis. All detached, devitalized skin, soft tissue, and bone should be sharply excised. There is much debate concerning the most appropriate method of irrigation. We recommend irrigation with either gravity-flow (i.e. with cystoscopy tubing or a bulb syringe) or low-pressure pulsatile lavage. High-pressure pulsatile lavage has fallen out of favor after mounting evidence showing it can lead to bacterial rebound, has the potential to push contaminated or infected tissue further into the soft tissues, and can even damage the tissues leading to edema, potentially compromising wound closure. The nonscientific recommendation of 3 liters for a type 1 Gustilo-Anderson open fracture, 6 liters for a type 2, and 9 liters for a type 3 has been handed down through the years. We usually use 9-12 liters depending on the degree of injury and presence of contamination. Typically, we use normal saline while others recommend castile soap, bacitracin, or other antibiotic solutions. The wound should usually be left open and typically requires serial debridements, typically recommended every 48-72 hours. Leaving a traumatic wound open allows for the tissues to declare themselves as those that can maintain perfusion and can be preserved or those that go on to ischemia and necrosis and require timely excision. The historical guillotine amputation has rare indications these days, except in the case of an initial guillotine amputation at a distal level with the intention to return for a staged, more proximal limb reconstruction (i.e. index guillotine ankle disarticulation with a mangled, nonviable foot prior to a planned revision to a transtibial amputation).

The wound vacuum sponge and negative pressure therapy has revolutionized wound management as it has been shown to lower infection rates and improve healing rates. Vessel loops are a helpful adjunct when placed in a Jacob's Ladder or Roman Sandal fashion over the vacuum sponge. The timing of definitive closure remains highly subjective and depends on multiple variables including the condition of the tissues, the patient's health condition, laboratory values, and possibly culture results. With infectious indications for or complications from amputations, some would argue leaving a wound open and serially washing and debriding until tissue cultures or intraoperative histology are negative.

In addition to negative pressure wound therapy, antibiotic-impregnated polymethylmethacrylate (PMMA) cement and other cement formulations (i.e. calcium-phosphate) in the shape of beads, cubes, or rods have proven helpful in eradicating deep infection in trauma-related amputations. Various techniques and substances (i.e. dermal allograft) exist to create a bead pouch that can temporize an infected or contaminated open wound. Antibiotic cement can even be used to span a bone defect to preserve length. With this technique, the hope is that a pseudomembrane will form around the cement allowing for eventual bony reconstruction. Typically, antibiotic beads and the like are covered with a wound vacuum in anticipation of delayed primary closure. Most commonly, vancomycin and gentamicin are used but a variety of formulas have been created. Surgeons should be aware that the majority of the antibiotic elution occurs in a rather short time frame and eventually the cement (specifically PMMA) itself becomes a nonantiobiotic foreign body and potential nidus for infection, which highlights an advantage of the resorbable cements (i.e. calcium-phosphate).

Closed suction drainage is a controversial topic and should be at the discretion of the surgeon. Use of a drain may increase the need for postoperative blood transfusion, which has been shown to increase the infection risk in the arthroplasty literature. Additionally, a drain is a theoretic portal to the outside world and edema can be effectively marginalized with postoperative casting and strict elevation.

Amputation Level and Length Preservation

Some would argue that the benefit of preserving length with an amputation through the zone of injury might outweigh the elevated risk of wound complications and heterotopic ossification. The exceptions may be in grossly contaminated wounds and blast injuries. As touched on earlier, energy expenditure is increased as the amputation level moves proximally in the lower extremities. The gait efficiency of an amputee is compromised, evidenced by increased rates of oxygen consumption and slower walking speed. The loss of the ankle and knee in transtibial and transfemoral amputations respectively is the major hindrance to an unencumbered gait. The ankle and knee serve to allow motion but also to transmit load and with the sacrifice of these joints, load is borne in a less efficient and likely more eccentric fashion. Additionally, from the amputation level proximally usually lie weakened muscles, including that at the thigh and hip, placing more strain on the pelvis, low back, trunk, and well limb, exhausting compensatory mechanisms, further interfering with natural gait, and increasing the energy cost. Secondary to these considerations, joint-level preservation leads to better outcomes and a longer residual limb given that doing so does not come at the cost of quality soft tissue coverage. Length preservation is possible through the retention of grossly viable tissue, allowing these so-called "flaps of opportunity" to mend and potentially be useful in soft tissue and bony coverage. As much length as possible of the residual limb should be preserved to allow for the optimal reconstruction option and minimize the increase in energy expenditure with a prosthesis. In rare instances, free tissue transfer can be utilized to salvage a functional, distal joint level in the absence of healthy, local coverage. Skin grafts (in rare instances a dermatomal harvest from amputated tissue) and soft tissue expanders can also help preserve residual limb length.

Traditionally, fractures of the residual limb well after an amputation have been treated nonoperatively or with a more proximal amputation. However, recent work from the battlefield has made orthopaedists in general more aggressive in their surgical fixation of these fractures in patients with favorable rehabilitative potential.

Neurovascular Considerations

All named peripheral nerves, including visible cutaneous ones, should be clearly identified and managed with a traction neurectomy well proximal into the residual limb to prevent symptomatic neuromas. Some argue that slow electrocautery as opposed to sharp transection may reduce the chance of a symptomatic neuroma. Other techniques have been described including epineural and silicone capping, preemptive regional anesthetic blockade, and implantation of the cut nerve end into muscle or bone without convincing results. Suture ligation should be considered with larger nerves to reduce the risk of bleeding from the vasa nervorum. Neuroma formation is inevitable as regenerating axons attempt to penetrate the distal nerve stump and is a common reason for revision amputation. The key is to prevent them from becoming symptomatic with prosthetic wear. Neuromas can become symptomatic with routine stimuli including stretching, light pressure, and vascular pulsations. The most common sites in the lower extremities are the common peroneal and sural nerves. The common peroneal nerve is relatively tethered around the fibular neck and may become symptomatic after a transtibial amputation with prosthesis wear. The sural nerve is subcutaneous and often ignored during a transtibial amputation.

In a similar manner, all named vessels should be identified, isolated, and securely ligated with nonabsorbable suture (i.e. silk ties). It is often prudent to let the tourniquet down prior to wound closure to ensure hemostasis and eliminate the risk of a postoperative hematoma. All sharp bony ends should be smoothed and, as in fracture work, the periosteum should be respected in its role of supplying a third of the bone’s blood supply.

Muscle Management

The length-tension relationship of surrounding musculotendinous units should be preserved with a stable, durable myodesis and myoplasty augmentation if needed to preserve residual limb control, alignment, and prevent proximal joint contractures. Myofascial techniques should focus on providing a well-padded distal bony end to protect against pressure and shear forces. Myodesis is the most mechanically stable and can allow for functional muscle use during walking. It involves fixing residual muscle and its investing fascia to bone via sutures and typically drill holes or suture anchor devices. Myoplasty is done by suturing a residual agonist muscle to its antagonist over the end of the bone to create physiologic tension. Myofascial closure involves suturing a residual muscle and its apposing fascia together, creating the least stable of the muscular constructs. Myoplasty and myofascial closures should serve to supplement a myodesis to grant patients the best chance of a functional, controlled limb. Overall, the wound should be balanced and well-padded to avoid pain, ulcerations, and necrosis from the underlying bony end. Close, frequent follow-up is vital to identify and address complications early.

Amputation versus Limb Salvage

Much work has been done this past decade with regard to the decision-making involved in limb salvage versus amputation in high-grade open fractures or mangled extremities, most notably the Lower Extremity Assessment Project (LEAP) Study. Orthopaedists seem to still amputate the more severely traumatized limbs. It has been hypothesized that patients undergoing amputations after severe lower extremity trauma would have better outcomes than those undergoing limb salvage. However, outcomes with both treatments result in a significant proportion of disabled patients with similar early costs for both groups. In the long run amputees accrue more expenses over their lifetime secondary to prosthesis-related costs. An amputation is not always the best treatment for severe lower extremity injuries as they carry a host of potential complications including residual limb, phantom-limb, low back, and proximal ipsilateral or contralateral joint pain. Low back pain seems to be the most common disabling pain after an amputation and the incidence is increased in those with amputations above the knee. A recent report of war-related amputations described an increased risk of amputees developing and dying of cardiovascular disease than a matched control. Surgeons always hope to return their patients to their original vocation, but often amputees have to change occupations postoperatively.

The LEAP study went on to show that various injury scoring systems (i.e. Mangled Extremity Severity Score) were not reliable predictors of the surgical outcomes of affected limbs and poorly predicted patient outcomes. The study refuted a traditional belief that an insensate foot was an indication for amputation as they found that plantar sensation returned in the majority of patients in two years. They did find certain predictors of a poor outcome including low educational level, poverty, a poor social support network, smoking, and involvement of the patient in disability-compensation litigation.

A preponderance of the literature investigating traumatic lower extremity amputations deals with open tibia fractures. Indications for amputation in the lower extremity include a blunt or contaminated traumatic amputation, a mangled extremity in a critically injured patient with multi-system organ failure, a crushed extremity with an arterial injury, and a warm ischemia time of greater than six hours. Softer indications include severe bone or soft tissue loss, an anatomic transection of the tibial nerve, an open tibia fracture with associated significant polytrauma and an ipsilateral mangled foot, and an anticipated protracted course to obtain soft tissue coverage and bony reconstruction. It is common practice for two qualified surgeons to evaluate the patient intraoperatively and come to a consensus with regard to limb salvage versus sacrifice.

Pain Management

There is a real correlation between the level of acute and chronic postoperative pain. Early phantom-limb pain usually predicts persistent symptoms. Current analgesia techniques strive to increase patient comfort, decrease requirements for addictive narcotics, and grant earlier mobilization. The goal is to prevent central neuroplastic remodeling from occurring through the use of preventative multimodal analgesia. Various modalities take aim at the various pathways of nociception, including anticonvulsants like gabapentin, non-steroidals, local nerve-sheath injections, alpha-2 agonists, ketamine, opioids, preemptive epidural injections, and regional nerve blocks. Surgeons should routinely involve pain management specialists to minimize acute and chronic postoperative pain.

Psychosocial Impact

It has been shown that a generous proportion of patients undergoing an amputation will develop a psychological disorder, even in the most highly functioning and stoic patients. Counseling, if possible, should begin preoperatively and various care programs should be involved early on in a patient’s course.

Specific Amputation Levels

The specific anatomy at each amputation level is not described in detail. Rather, the salient points with regard to assurance of a sound, stable, well-padded, biomechanically favorable amputation are presented. Many of the principles discussed can be applied to amputations in general, regardless of the extremity and level.

Transmetatarsal

A transmetatarsal amputation (TMA) level is most commonly indicated in trauma and soft tissue loss and infection, specifically gangrene in brittle diabetics. Postoperatively, patients require shoe modification and inserts to fill the forefoot space. A clear, circumferential zone of healthy tissue must be intact to amputate through an area proximal to the metatarsophalangeal (MTP) joints. Energy expenditure is not increased with this amputation level, but gait is often affected by the awkward fit of shoes and forefoot-replacing inserts. The arch often flattens out over time necessitating a molded, medial arch to supplement the toe filler and an extended steel shank can add protection during rollover.

The skin incision must lie proximal to the traumatized or infected tissue and soft tissue coverage is gained entirely from the plantar flap. The incision begins at the mid-lateral point of the foot and extends medially and dorsally over the midportion of the metatarsal shafts in a slightly curved fashion. The incision is carried along the plantar surface at just proximal to the MTP joints. There is greater cross-sectional area to be covered medially so the plantar flap should be extended more distally on the tibial side of the foot. The soft tissue on the sole of the foot is sharply cleared from the plantar surface of the metatarsals and the extensor tendons are sharply divided while the plantar musculature is left apposed to the plantar skin flap. The metatarsal shafts should be cut in a dorsal-distal to proximal-plantar fashion with a electrical saw 5 mm to 1 cm proximal to the dorsal wound edge in a cascading fashion reflecting the decreasing ray length from the great to the small toe. Irrigation should be used in all bony cuts to avoid thermal necrosis of the bony ends and the surgeon should always be cognizant of the soft tissue on the other side of the cut to avoid inadvertent damage. The plantar flap is then delivered dorsally and thinned as needed to have an intimate fit of the wound edges. Absorbable, interrupted sutures are placed in the deep tissue and the skin edges are then closed in a tension-free environment with the sutures placed in a horizontal or vertical mattress manner. Amputation wounds in diabetics should always be protected longer with closer follow-up and strict glycemic control.

Transtibial

The below-knee amputation is probably the most commonly performed, especially in trauma, and has been associated with the best functional outcomes. Knee dysarticulations have been popularized recently but are typically a poor option in trauma because they result in the slowest walking speed and least satisfaction and typically are lacking of adequate stump soft tissue coverage. With a BKA, patients typically enjoy a high rate of prosthetic use, minimal or no disability, their gait is fairly well preserved, and retaining the knee joint minimizes energy expenditure. If the amputation level is not strictly dictated by the injury pattern, extent of infection, or presumed safe tumor margins, 2.5 cm of tibia should be preserved for every 30 cm of body height. This generally translates into 12.5-17.5 cm of residual limb length with surgeons erring on the side of a longer residual limb if there is adequate soft tissue coverage. The length of the posterior myofasciocutaneous flap should approximate the anteroposterior diameter of the leg at the level of the amputation plus up to 3 cm. The anterior tibial periosteum is sharply elevated 1 cm distal to the wound edge and retracted back proximal to the skin edge and bony cut and serves as the docking site for the posterior flap. Some argue that it is easier to cut the fibula first because the tibiofibular articulation makes the fibula more stable and easier to saw. The fibula should be cut 1-2 cm proximal to the tibia; any higher may result in a conical stump, making the tibia too prominent and potentially compromising socket fit. The bone should be cut with an electrical saw proximal to the anterior wound edge and the anterior cortex should be beveled 45(to avoid pressure on the posterior flap. The soleus is excised and the gastrocnemius-based posterior flap is then brought anteriorly and sewn with heavy, absorbable suture to the anterior tibial periosteum. Myodesis of the posterior flap can also be augmented or performed via two bone tunnels in the tibial stump and #5 nonabsorbable suture in a horizontal mattress manner. This traditional method of bringing the posterior flap to the anterior wound edge places the suture line anterior in relation to the stump, minimizing wound complications.

Preoperative plain radiographs are used to detect the presence of any proximal tibiofibular instability. If instability is present, the fibula should be stabilized to the tibia distally via a bone-bridging synostosis (i.e. osteomyoplasty) to provide a broader, more durable end-bearing stump and to prevent symptomatic motion between the cut tibia and fibula, so-called chop-sticking. Usually a cut portion of the fibula is positioned to bridge the fibula to the tibia at their stumps and stabilized with prolonged immobilization or fixed with a screw or deployable suture device. It is debatable whether outcomes are improved with this technique originally described in World War I and modified over the past seventy years. Complications involved with osteomyoplasty include symptomatic nonunion, malunion, bone-bridge dislocation, and implant-related complications.

Transfemoral

At this more proximal level above the knee, the absence of the knee joint results in a less efficient gait, increased energy expenditure and resulting in poorer outcome scores. Given the already compromised gait, strict biomechanical principles must be adhered to with this amputation level. A fish-mouth incision is made distal to the planned bone cut that is generally employed approximately 10 cm proximal to the knee joint line, but the surgeon can go as far distal as the superior pole of the patella. The adductor myodesis is perhaps the most critical step of the procedure to maintain as much native gait mechanics as possible and prevent the flexion/abduction deformity of the residual limb if the abductors were left unopposed. If the adductor mass is not reattached, the residual thigh mass atrophies and thigh strength plummets, gradually allowing for lateral drift of the residual femur in the soft tissue envelope. When this occurs, the remaining hip musculature is unable to adequately support the pelvis, further decreasing gait efficiency. Some advocate incorporation of the medial hamstrings in the myodesis to further counterbalance not only the strong abductor moment but also the hip flexors. Typically, the adductor mass, iliotibial band, and hamstrings if desired are transected 4-5 cm distal to the skin incision and secured to the distal femoral stump via drill holes and heavy nonabsorbable suture with the residual limb in maximum adduction to maintain the length-tension relationship on the medial side of the femur. Myoplasty of the quadriceps expansion (the medial and lateral retinacular and distal extent of the quadriceps tendon) and biceps femoris is then performed to maximize padding and create a cylindrical stump.

Postoperative Care

Conflicting management philosophies exist and include soft and rigid dressings and the immediate postoperative prosthesis (IPOP). An IPOP was designed during World War I to immediately fit amputees with a temporary prosthesis. This device includes a connector and pylon and foot that are attached to a cast or thermoplastic socket immediately after amputation. Each method has its advantages and disadvantages. When used appropriately, most methods are efficacious and none has proven superior clinically. Whatever technique is implemented, it is imperative to provide well-balanced, adequate compression to reduce swelling, decrease pain, and arrive at a stable limb volume. Elastic shrinkers are helpful in reducing swelling as well. Their timing may be early or may be at the surgeon’s discretion of when the wound has healed adequately to prepare the limb for prosthetic fit and wear. Therapy should start early to restore strength, balance, motion, and prevent contractures. The timing of weight-bearing is often debated. Some advocate refraining until total wound healing whereas others start sooner and feel earlier, symmetrical load through the stump can reduce swelling, improve perfusion, and rehabilitate patients faster resulting in lower costs and shorter hospital stays. Soft dressings are useful to administer serial wound checks and eliminate the risk of a pressure ulcer or thermal injury from a splint or cast. Benefits of the IPOP specifically include improved psychological satisfaction, less perceived loss of function, shorter hospital stays, fewer revision operations, and shorter time to index prosthetic fitting. Downsides include increased expense, possible wound compromise, and the inability to detect early complications at the stump. With transmetatarsal amputees, weight-bearing should be limited until adequate wound healing, especially in diabetics. In transtibial amputees, prevention of a knee flexion contracture is vital, usually swaying surgeons towards a rigid postoperative dressing.

Exhaustive nonoperative management should be adhered to for the majority of postoperative complications with the exception of a failed myodesis including bone spurs, heterotopic ossification, symptomatic neuromas, wound complications, and redundant soft tissue in the form of “dog ears.”

Osseointegration

Osseointegration is an experimental technique that involves the mating of the residual limb and a synthetic component with the hopes of providing durable function without rejection. A titanium rod is screwed into the residual bone, and then often in a staged fashion, is brought through the skin and soft tissue to allow prosthetic attachment. Theorized benefits include quick and easy placing and removing of the artificial limb, direct force transmission, a consistent, proper fit, no restriction of the proximal joint, and no socket or liner that can cause sweating and skin slough or mottling, sores, and discomfort. This technique carries the risk of substantial complications including infection, osteolysis, and periprosthetic fracture. Revision amputation for failed osseointegration usually involves proximal migration of the amputation level with the associated gait dysfunction and increased energy burden as detailed above.

CONSIDERATIONS FOR UPPER EXTREMITY AMPUTATIONS

Introduction

Amputation of the upper extremity is a catastrophic event most commonly performed in the setting of high-energy trauma in a young, healthy, productive population. As opposed to the lower extremity, upper extremity amputations are rarely performed in elderly and indications less commonly include diabetes and peripheral vascular disease. Limb salvage considerations from the lower extremity do not practically apply to the upper extremity given the irreplaceable function of the human hand. Despite leaps in technology motivated from the battlefields in Afghanistan and Iraq, functional capabilities of upper extremity prostheses significantly lag behind the degrees of freedom, dexterity, and sensory feedback of the native arm, forearm, and hand. In contrast to the lower extremity where a “good amputation” may be better than a “bad foot”, in the upper extremity a “bad hand” may be more functional than a “good amputation.”

Certain aspects of the upper extremity make it more amenable to salvage or replantation. Due to the increased density of nerve endings and fine motor capability, increased collateral circulation prolongs ischemia time and may allow for an extended time to reperfusion, quoted as long as 8-10 hours after a vascular injury. Additionally, the upper extremity is relatively non-weight-bearing, making limb length less of a concern, allowing for shortening osteotomies to protect primary neurovascular repairs and primary soft tissue closure. Similarly, patients can more easily limit weight-bearing through the upper extremities and adhere to postoperative activity restrictions, reducing the frequency of direct pressure and shear on the wound. Unlike the lower extremity where delayed weight-bearing is necessary to protect flap coverage, in the upper extremity this is typically not an issue and thus does not interfere with mobilization and rehabilitation.

Outcomes have been compared between upper extremity replantation and revision amputation and prosthetic fitting. The authors concluded that those treated with replantation had better function on the Carroll Standardized Evaluation of Integrated Limb Function years after their injury. This outcome measure assesses a patient's ability to grasp, grip, pinch objects, position their hand and objects in space, write, and perform other complex motions. It was concluded that if prehension at all the digits was achieved, replantation was superior.

Length Preservation

The upper extremity functions to position the hand in space. The more length that is preserved, the more capable patients are of feeling, taking hold of, and manipulating objects in their environment. When the residual soft tissue is such that wound closure is not possible without limb shortening, consideration should be given to alternative coverage options including split-thickness skin grafting (or dermal allograft if the host tissue bed is not amenable to primary skin grafting), a pedicled flap, or a free tissue transfer. The fitting of a prosthesis can be a challenge if flap coverage distorts the stump, and the surgeon should always consider the size, shape, durability, and cosmesis of the residual limb. Sound indications for free tissue transfer to preserve length have been studied and include shoulder and elbow joint preservation, bone preservation > 7 cm below the shoulder or elbow (to improve prosthetic fit and performance), and less so for wrist preservation.

Neuromuscular Principles

Most of the surgical principles laid out for the lower extremity apply to the upper extremity. In the upper extremity, an intricate knowledge of the peripheral nerves and their innervations is paramount to carefully perform traction neurectomies and preserve as much muscle as possible to avoid atrophy of muscles serving as padding of the residual limb, muscles to provide control for a myoelectric prosthesis, and terminal nerve branches that can be transferred in a non-anatomic fashion for targeted muscle reinnervation. The length-tension relationship of the muscles in the residual limb should be closely approximated via myodesis, myoplasty, and myofascial closure to provide padding of the bony ends, prevent retraction, simulate resting muscle length, and improve contractility characteristics, improving the control with or without a myoelectric prosthesis. As in the lower extremity, myodesis is preferred in the upper extremity because myoplasty can lead to painful bursa formation over the prominent bony end and can result in signal spread and involuntary co-contraction of antagonistic muscles, interfering with myoelectric signal detection.

Specific Amputation Levels

Transradial

The transradial amputation is the most common in the upper extremity. It is typically pleasing cosmetically and allows for fit of a body-powered or myoelectric prosthesis with quick-disconnect components while maintaining limb length. The maintenance of the shoulder and elbow and of some forearm pronation and supination allows a terminal prosthesis at the end of a long lever arm to be easily positioned in space. When possible, two-thirds of the forearm length should be preserved with resection of 6-8 cm of bone to allow for ideal soft tissue coverage of the residual limb and permit an array of prosthetic options. Some advocate interposition of soft tissue between the distal radius and ulna to avoid painful convergence and instability; the pronator quadratus can be used more distally while a flexor and extensor can be used more proximally. The favorable outcome of this amputation should push the surgeon to exhaust all reconstructive soft tissue coverage options to achieve this level.

If the situation dictates a more proximal forearm level, little functional pronation and supination can be maintained. Only 5 cm of residual ulna is required for prosthetic fitting and to preserve elbow flexion. If the ulna is shortened further, a distal biceps tenodeses should be performed from the radial tuberosity to the ulna. Rehabilitation should focus on preventing a flexion contracture at the elbow. A short proximal ulna can serve as a robust end weight-bearing surface and should be considered in those relying on their upper extremities for mobilization due to lower extremity injuries.

Transhumeral

Distal transhumeral amputations maintain the metaphyseal flare of the distal humerus, allowing for improved suspension and better rotational control of a prosthesis than a more proximal amputation level. Ideally, 3-5 cm of distal humerus above the elbow joint should be preserved. An angulation osteotomy may be performed to create an angulated, residual distal humerus to improve suspensory and rotational control of a prosthesis, similar to that achieved with an elbow dysarticulation.

With proximal transhumeral amputations, every effort should be made to preserve at least 5-7 cm of residual humerus to favorably affect prosthesis suspension and acceptance. Skin grafting or free tissue transfer (i.e. latissimus dorsi) should be employed to preserve this length if necessary. The deltoid should be preserved even in very proximal levels to allow active elevation of the humeral head within the glenoid. The humeral head should be salvaged whenever possible to preserve the attachments of the rotator cuff muscles and their force coupling function, keeping the humeral head depressed and concentrically reduced within the glenoid during deltoid-activated shoulder elevation. Maintenance of the humeral head also improves cosmesis and potentially allows for a myoelectric or body-powered prosthesis. The insertions of the pectoralis major, latissimus dorsi, and deltoid must be retained or reconstructed; otherwise the result of a proximal transhumeral amputation will be that of a shoulder dysarticulation with regard to prosthetic fitting. Additionally, if the humeral head remains for cosmesis and to aid in force transmission, glenohumeral arthrodesis can be considered in a staged fashion to prevent any painful or disfiguring abduction contracture or joint subluxation, which may occur if the rotator cuff is left unopposed.

Outcomes

An upper extremity amputation is a profoundly life-altering event. Prehension and touch sensation cannot be replicated by modern prostheses. Rates of rejection of upper extremity prostheses approach upwards of 30%. These poor acceptance rates result from poor cosmesis, limited limb usefulness, prosthetic weight, residual limb/socket discomfort, poor training, delayed fitting, and most notably, more proximal amputations. Factors associated with prosthesis acceptance include loss of the dominant limb, a painless residual limb, and fitting within thirty days of the amputation. It is generally accepted that functional scores and prosthesis acceptance rates are higher the more distal the amputation level. Transradial and transhumeral amputees report the highest and second-highest prosthesis utilization rates respectively. As expected, shoulder dysarticulation outcomes are the poorest. In the setting of a healthy, stable distal radioulnar joint, wrist dysarticulation can preserve full forearm rotation and eliminates the risk of painful impingement of the distal radius and ulna. The large surface area of the distal radius allows for rather symmetrical weight-bearing and the long, sensate residual limb increases a person's functional reach and accepts a prosthetic socket well. An elbow dysarticulation maintains the distal humeral condyles and has similar benefits to the distal transhumeral amputation. The major downside is cosmetic because typically the prosthetic elbow joint is distal to the contralateral elbow or external to the plane of the humerus and prosthesis. Of note, the literature has shown that people with bilateral upper extremity amputations will almost universally use at least one prosthesis and those with an ipsilateral brachial plexus palsy will routinely reject a prosthesis. Phantom-limb pain is quoted as occurring in > 50% of patients after an upper extremity amputation, although it is encouraging that it typically does not impede functional prosthetic wear or the ability to return to gainful employment. As discussed in the lower extremity section, metachronous pain can occur with amputations, and in the upper extremity can affect the back, neck, and contralateral, well limb.

Prosthetic Design

Modern myoelectric prostheses typically use a forceps-type distal device that allows a solitary degree of freedom with high-magnitude grip strength. Recently, improved, lightweight, efficient, and durable materials, have allowed for the creation of a more anthropomorphic upper extremity with multiple degrees of freedom and grasping patterns with less necessary overall grip strength. On-board intelligent sensors will someday provide tactile feedback loops capable of real-time determination, feedback, and adjustment of touch, slip, position, and temperature. The neural-prosthesis interface is constantly being improved upon with improved electromyographic sensors as researchers work towards someday achieving implantable electrodes and a sensory interface.

Targeted Muscle Reinnervation

Patients with amputations at or above the elbow encounter difficulties precisely controlling prostheses because the muscle contractions necessary to signal the device are not intuitive and the remaining muscles provide indistinct signals to control more than one prosthetic joint simultaneously, leading to slow, sequential, alternating control at each joint. Targeted muscle reinnervation was developed to improve control of myoelectric prostheses. The premise revolves around regaining the signaling ability of the nerves that formerly innervated the amputated limb through novel nerve transfers. No function is lost as the formerly innervated muscles are gone. The reinnervated muscle units transduce the transferred nerve's original function, capable of more precisely controlling the prosthesis. For example, in transhumeral amputations, five independently controlled nerve-muscle units are obtained by transferring the distal radial nerve to the motor branch of the lateral head of the triceps, the median nerve to the motor branch of the medial head of the biceps, and possibly the ulnar nerve to the motor branch of the brachialis if available. These transfers provide the signals for intuitive hand opening and closing and potentially finger spread. These patients maintain the ability to flex and extend the prosthetic elbow.

Some work has been done with matching an individual's specific natural, voluntary EMG patterns with a patient's prosthesis, a technology called advanced pattern recognition that may someday produce a custom prosthesis capable of performing rather complex movements.

Tuberculosis of the Spine

Timothy C. Mead, MD

Introduction:

Tuberculosis of the spine has been a problem for millennia. Egyptian mummies from 3000BC have been discovered with findings of spinal tuberculosis. Sir Percival Pott in 1779 was the first to publish a description of spinal tuberculosis associated with paraplegia. Even today many people refer to spinal tuberculosis as 'Pott's Disease.' Despite many advances in medical care tuberculosis remains an international tragedy. The WHO estimates approximately 30million people in the world have tuberculosis. Every year 9million new cases of tuberculosis are added to this number.(WHO2008) The greatest numbers of people affected by tuberculosis are found in India, China, South Africa, Nigeria, and Indonesia. Approximately 15% will also be HIV positive. (WHO 2010) Tuberculosis is commonly thought of as a disease affecting the pulmonary system. Many people will have presentations in the hips, knees, abdomen, brain, and spinal column. Tuberculosis can be a grand mimic of other disease processes and must remain in the differential diagnosis. Approximately 2-3% of all tuberculosis cases will affect the spine. Of those TB spinal cases the thoracic spine is the most common affected. The cervical spine has the greatest danger of paralysis and death. The lumbar spine has the greatest tolerance of disease without paralysis.

Etiology:

Mycobacterium tuberculosis is the causative organism in the vast majority of spinal tuberculosis cases. The laboratory studies demonstrate acid fast positive caseating granulomas. There may be surrounding pus cells as well. TB grows forming expanding abscesses which follow paths of least resistance. Skin sinuses are common which open to drain and then close spontaneously.

In the spine Tb spares the discs and spreads beneath the anterior and posterior longitudinal ligaments. As the bone is destroyed there is a collapse which has been described as accordion-like.

Presentation:

Early in the course of the disease the patient will have vague constitutional symptoms: malaise, fever, weight loss, fever. Laboratory studies may show mild anemia and low proteins consistent with a chronic disease process. Sedimentation rates are often normal or mildly elevated.

Later in spinal TB the patient develops back pain. Often in a child this is diagnosed as secondary to the forgotten fall or elusive 'strain.' As the pain persists too often the parents are given the same story by others. Often the pain increases and a 'bump' develops- the vertebra has collapsed.

In the terminal stages of the progress the patient may present with weakness in the extremities and even complete paraplegia. Even at this stage there is still hope for recovery.

Radiology:

Plain films will initially show a subtle decrease in disc space height. The anterior end plates and vertebral bodies will have decreased bone density. As the disease progresses the bone is destroyed and becomes more wedged shaped. Finally, the bone is eaten away developing a local kyphosis. The amount of bony involvement will determine the degree of kyphosis and the risk of further collapse. Soft tissue swelling about the vertebral column heralds the formation of large abscesses.

CT scans are helpful if available to determine the degree of bony involvement. CT scans aid in the decision process of instability and potential instability of the spine. As the columns of support are destroyed the risk of instability and therefore paraplegia increases.

MRI images will allow the definition of soft tissues well. Abscesses can be traced into the spinal canal. Dural compression can be defined. Epidural extensions are visualized.

CT and MRI scans are very good, costly tools but do not take the place of a good physical examination and plain x-ray films. Reasonable treatment plans can be made even if the CT or MRI scans are not available for patient care.

Differential Diagnosis:

- Fungal infections
- Brucellosis
- Metastatic tumor
- Multiple myeloma
- Eosinophilic granuloma
- Aneurysmal bone cyst
- Osteosarcoma
- Scheuermann disease
- Giant cell tumors

Treatment:

Treatment options for spinal tuberculosis fall into broad categories including: medication alone (Both ambulatory and in-patient), surgery alone, combined surgical and medical treatments.

In 1960 Hodgson et al reported a series of 412 patients treated by radical debridement of all affected bone and anterior spinal fusion. His mortality rate was 2.9% with the majority of deaths in advanced cases. No patient developed paralysis following this treatment option. Late spinal kyphosis was avoided by a rigid anterior fusion. Hodgson recommended the adoption of this procedure for the treatment of all cases of spinal TB.

The Medical Resource Council Working Party generated many reports of multiple sites studying the operative and non-operative methods. They found if there was existing paraplegia the results of operative versus non-operative were the same. The studies also found better results with radical debridement and chemotherapy with respects to recurrence, progressive deformity, resolution, and late onset paraplegia.

One of the complications of anterior spinal fusion is graft failure. With rib strut or fibular grafts there is a large bending moment on the construct. Up to 30% of the grafts may fail; the spine will then collapse into kyphosis. Abnormal kyphosis destroys the normal spinal biomechanics and places the spinal cord and nerve roots at risk. As spinal fixation and implants have evolved combined procedures have improved the stability and fusion success rates.

Anterior surgical radical decompression has been combined with posterior spinal instrumentation and fusion to stabilize the spinal unit. Surgery is followed by chemical treatment of the tuberculosis using multidrug protocols. Posterior options include rods and hooks, rods and sub laminar wires, rods and pedicle screws, and spinous process wires (cervical spine). All techniques have advocates but require the necessary surgical skills.

Anterior radical decompression and fusion can also be now combined with anterior fixation devices. A variety of options exist but all require experienced surgeons.

Laminectomy alone should never be done. Laminectomy will further destabilize the spine so that all columns are affected and the risk of instability great.

Indications for surgery are dependent on several factors. First is the availability of experienced surgeons to perform the procedures. Second, there must be the hospital capability to care for the patient. All components of medical care from laboratory services, anesthesia services, nursing care, TB medications and follow-up plans, chest tube drains, and radiology combine to form the treatment team. If all members of the team are not present the surgical risks are substantially increased and surgery best avoided.

If there are the needed resources then other indications are reviewed. Although there is discussion in the literature and among clinicians the indications are becoming clearer. Surgery is recommended for patients with neurologic deficits, especially those that are progressive. Spinal kyphosis greater than thirty degrees or bony destruction at two or more vertebra is likely to progress. Progressive kyphosis means instability and should be addressed surgically. Surgery for diagnostic biopsy and treatment in the face of recurrent disease or resistant disease is warranted. The presence of a positive HIV status is not a contraindication for treatment unless the medical status is poor. The best surgical option currently would entail a radical vertebral debridement with fusion combined with either an anterior or posterior spinal stabilization procedure and followed by chemotherapeutic treatment of the tuberculosis for at least 6 months. Serial x-rays will be needed to follow the progress of the spinal healing and fusion.

Indications for chemotherapeutic treatment alone of the spinal tuberculosis are for those patients who have no radiographic signs of spinal instability, advanced pulmonary or cardiac compromise, or the absence of experienced surgeons and treatment team members.

Conclusion:

Spinal tuberculosis is an uncommon but potentially devastating disease process. Early intervention will avoid major surgical procedures and give good results. When there has been late onset paralysis or paralysis that has been present greater than six months the prognosis for recovery is poor. Paraplegia in the developing world is a lethal disease with few patients living more than a couple of years. A high index of suspicion, early spinal x-rays especially in children, and follow-up check-ups will avoid major complications.