



18 ORTHOPEDICS & REHABILITATION

JON MUKAND, MD, PhD
GUEST EDITOR



19 Rehabilitation for Total Joint Arthroplasty
SCOTT RITTERMAN, MD; LEE E. RUBIN, MD



23 Management of Ankle Fractures
RAYMOND Y. HSU, MD; JASON BARITEAU, MD

28 Essentials of Anterior Cruciate Ligament Rupture Management
STEPHEN A. KLINGE, MD; GREGORY A. SAWYER, MD;
MICHAEL J. HULSTYN, MD



33 Diagnosis and Management of Lisfranc Injuries and Metatarsal Fractures
HEATHER E. GOTHA, MD; CRAIG R. LAREAU, MD;
TODD A. FELLARS, MD

37 Nerve Compression Syndromes of the Upper Extremity: Diagnosis, Treatment, and Rehabilitation
P. KAVEH MANSURIPUR, MD; MATTHEW E. DEREN, MD;
ROBIN KAMAL, MD

Orthopedics & Rehabilitation

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A variety of orthopedic conditions can lead to pain and disability. As the American population ages, the prevalence of musculoskeletal disability will increase due to conditions such as osteoporosis, osteoarthritis, and trauma from falls. Recent data show that one million total hip and knee replacements are performed annually in the United States, typically because of osteoarthritis.¹ Every year, more than 325,000 people in the United States – usually women with postmenopausal osteoporosis – have hip fractures after falls, with devastating consequences: a one-year mortality rate of about 20% and in-hospital mortality of 2.7%.² One third of older adults fall each year, and 20%-30% of this group suffer moderate to severe bruises, fractures, and head injuries.³ Among workers, there are nerve entrapment syndromes related to connective tissue changes. Carpal tunnel syndrome results from compression of the median nerve as it traverses the fibrous carpal tunnel, and has an incidence of 3%-5%.⁴ In the younger population, traumatic injuries due to sports and accidents result in knee ligament injuries as well as fractures of the foot and ankle.

My perspective on disability is that of a rehabilitation medicine specialist and medical director of the Southern New England Rehabilitation Center (based at Fatima Hospital). My center treats people with orthopedic conditions including multiple trauma, hip fractures, amputations, spinal stenosis that requires surgery, and joint replacements. (I should note that Medicare criteria for acute inpatient rehabilitation after hip/knee arthroplasties are strict: age 85 or greater, bilateral joint replacements, or morbid obesity; in addition, patients usually have medical comorbidities. Managed care organizations also have strict admission criteria.)



As a clinician and faculty member of the Orthopedic Surgery Department at Brown University, I often collaborate with the orthopedic residents. Therefore, I'm pleased that this issue of the *Rhode Island Medical Journal* is a forum for the medical writing of these residents and fellows. They have contributed articles on hip/knee replacements, knee ligament injuries, ankle fractures, foot fractures, and upper extremity nerve compression syndromes. While working on this special issue, the authors and I have tried to provide detailed information for accurate diagnosis and management by generalist physicians. (Of course, depending on the nature of the problem, it may be wise to consult an orthopedic surgeon.)

After receiving medical and surgical treatment in the acute care hospital, some people may require intensive inpatient rehabilitation at a facility such as the Southern New England Rehabilitation Center. Disability is a struggle, and I admire my patients, their families, and their surgeons as they contend with a variety of challenges. The admission criteria and the review process are complex nowadays, but we continue to enjoy working with our surgical colleagues on behalf of people with orthopedic disabilities.

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Rehabilitation for Total Joint Arthroplasty

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ABSTRACT

Total hip and knee replacement are two of the most common and successful elective surgeries performed in the United States each year. Preoperative medical preparation and postoperative rehabilitation are equally important to a successful outcome. Physical deconditioning, tobacco use, obesity and medical co-morbidities can adversely affect outcomes and should be addressed before any elective procedure. Formal postoperative therapy is geared towards the specific surgery and is aimed at returning the patient to independent activity.

KEYWORDS: Total Joint Replacement, obesity, rehabilitation, smoking, medical management

INTRODUCTION

Total hip and knee arthroplasty (THA/TKA) are two of the most common and successful musculoskeletal surgeries in the United States, accounting for over one million procedures annually. Osteoarthritis (OA) is by far the main cause in both hip and knee disease and it is increasingly prevalent.¹ As our population becomes more obese, less active, and lives longer, many more patients are seeking medical attention for pain relief. While the causes of OA are multifactorial (genetics, activity level, diet, weight, etc.), the final result is breakdown of cartilage, leading to weight bearing on eburnated bone. Ongoing inflammation irritates the surrounding soft tissues and leads to joint effusions, soft tissue contractures, and limb deformity.

By the time that most patients reach an orthopedic surgeon's office, many have exhausted conservative care due to advanced OA. Pain, deformity, and disuse lead to decreased independence and a poor quality of life. The essential goals of THA and TKA are to reduce pain and improve quality of life.

The process of rehabilitation after total joint arthroplasty (TJA) is often an afterthought for the patient, but is essential for the overall success of the procedure. We will discuss rehabilitation concepts for the pre-, peri-, and post-operative periods.

The Pre-operative Period

Pre-habilitation or "pre-hab" starts when the patient becomes a candidate for TJA and ends the day of surgery.

Often patients will schedule a joint replacement surgery one to four months in advance. In that time there is much to accomplish, and the main goals are as follows. Patients should be educated and should have reasonable expectations regarding TJA and its postoperative course. Home preparations should be made for eventual discharge and post-op care. In conjunction with the patient's primary care physician, the surgeon should work to address modifiable medical co-morbidities that can directly affect surgical outcomes (e.g. smoking, obesity, diabetic glucose control, and immunomodulating medications.) An exercise program with specific goals will aid in the recovery process; it should include strengthening the upper extremities (for using assistive devices) and lower extremities (via non-load-bearing exercises such as cycling, aquatic aerobics). Unfortunately, less than one third of patients with arthritis are actively engaged in some formal exercise program.²

Pre-operative educational classes can help address patient concerns prior to the operation.² In this setting, patients are free to ask questions and interact with other patients who will undergo the same procedures. In some instances, patients who have undergone a joint replacement can provide "firsthand" knowledge of the subject.

Weight loss is important for overweight or obese patients considering joint replacement surgery, as obesity carries a high risk of complications. A recent meta-analysis of numerous studies that included over 15,000 knee replacements found evidence that obese patients were significantly more likely to have a superficial infection, a deep joint infection, and a revision surgery (odds ratios (OR) of 1.9, 2.38, and 1.3 respectively).³ Overweight patients will also put more stress on the implants, potentially leading to early failure from mechanical overload.

Smoking inhibits bony ingrowth into prostheses and also impairs wound healing. Smoking cessation should begin in the primary care office and should ideally lead to at least one nicotine-free month prior to TJA. In a review of 33,000 TJA patients in the Veterans Affairs system, current smokers had a greater risk of surgical site infection (OR 1.4), pneumonia (OR 1.53), stroke (OR 2.61), and one-year mortality (OR 1.63) than those who had never smoked.⁴

Optimal glycemic management is another crucial issue that should be addressed preoperatively. Up to 8% of patients undergoing a TJA are diabetic, and uncontrolled diabetes is associated with higher rates of perioperative stroke, urinary

tract infection, ileus, transfusion, infection and death.⁵ An ideal “safe” value for the Hemoglobin A_{1c} has not been established to reduce the risks of surgical complications after joint replacement, but a goal of less than 8.0 is currently a reasonable threshold for elective surgery. This important test should be included with the pre-operative screening bloodwork for patients known to be diabetic.

The Peri-operative Period

This phase extends from surgery to hospital discharge. In the immediate post-operative period, patients who receive a total joint arthroplasty (TJA) can bear weight as tolerated (in most protocols). Pain control is of utmost importance, and a “multi-modal” combination of local anesthesia (perioperative block or regional nerve block), narcotics, analgesics, and NSAIDS are utilized in combination.

A typical hospital stay is two to three days. Ambulation should begin either the night of surgery or the following morning. In fact, a recent study demonstrated that patients who were mobilized on the day of surgery as opposed to the day after were discharged a day earlier on average. Additionally, shorter hospitalizations resulted in improved short-term outcomes and quality of life as well as decreased costs.⁶ Within the perioperative period, several decisions must be made, especially the discharge destination.

During the perioperative period, surgeons and patients

strive to prevent several complications. Bladder catheters are frequently used during TJA and have been linked to complications including urinary tract infections and delirium, so they should be avoided when possible, and removed as soon as possible when used. Incentive spirometry can help prevent atelectasis and pneumonia, especially in those with pre-operative pulmonary disease.

Finally, mechanical compression stockings and boots are used in conjunction with chemical prophylaxis for one month to prevent venous thromboembolic events (VTE). Clinical guidelines from the United States Preventative Service Task Force (USPSTF), American College of Chest Physicians (ACCP), Surgical Care Improvement Project (SCIP), and the American Academy of Orthopaedic Surgery (AAOS) are utilized to guide decision making for chemical VTE prophylaxis. Active exercises of the hip, knee, and ankle in combination with early and frequent ambulation during the patient’s recovery are strongly encouraged as additional means for VTE prophylaxis.

Postoperative Period

From the hospital, patients are either discharged home, to a skilled nursing facility, or to an acute rehabilitation hospital. Medicare standards currently allow acute rehabilitation for patients with bilateral TJA, morbid obesity, or age 85 or greater. Close communication and coordination between

the receiving facility and the operating surgeon are crucial to prevent complications and readmissions. Coordination of care between the patient’s primary care physician and the operating surgeon is also important during this period. The use of electronic medical records may help facilitate the accurate and timely transmission of this information.

Total Knee Replacement

There is general agreement that rehabilitating a total knee replacement is more difficult than a hip replacement. Patients typically make their greatest functional gains within the first 6 months after a THA and the first 12 months after a TKA.² The knee is a rotating hinge joint with an extensor mechanism (quadriceps, the patella and the patellar tendon) that originates at the pelvis and proximal femur and inserts on the

A typical pattern of arthritis is seen in this series of radiographs. There is tricompartmental arthritis, most pronounced in the medial compartment. In this patient the patella was not resurfaced with a polyethylene component.



tibial tubercle. During a total or partial joint replacement, the extensor mechanism is disrupted to a certain degree. In the standard approach, the quadriceps tendon is split at or near its origin, down through the medial patella and patellar tendon to the tibial tubercle. Moving the patella laterally allows access to the knee joint. An extensor mechanism that is well-aligned, repaired, and healed is essential to a successful knee replacement.

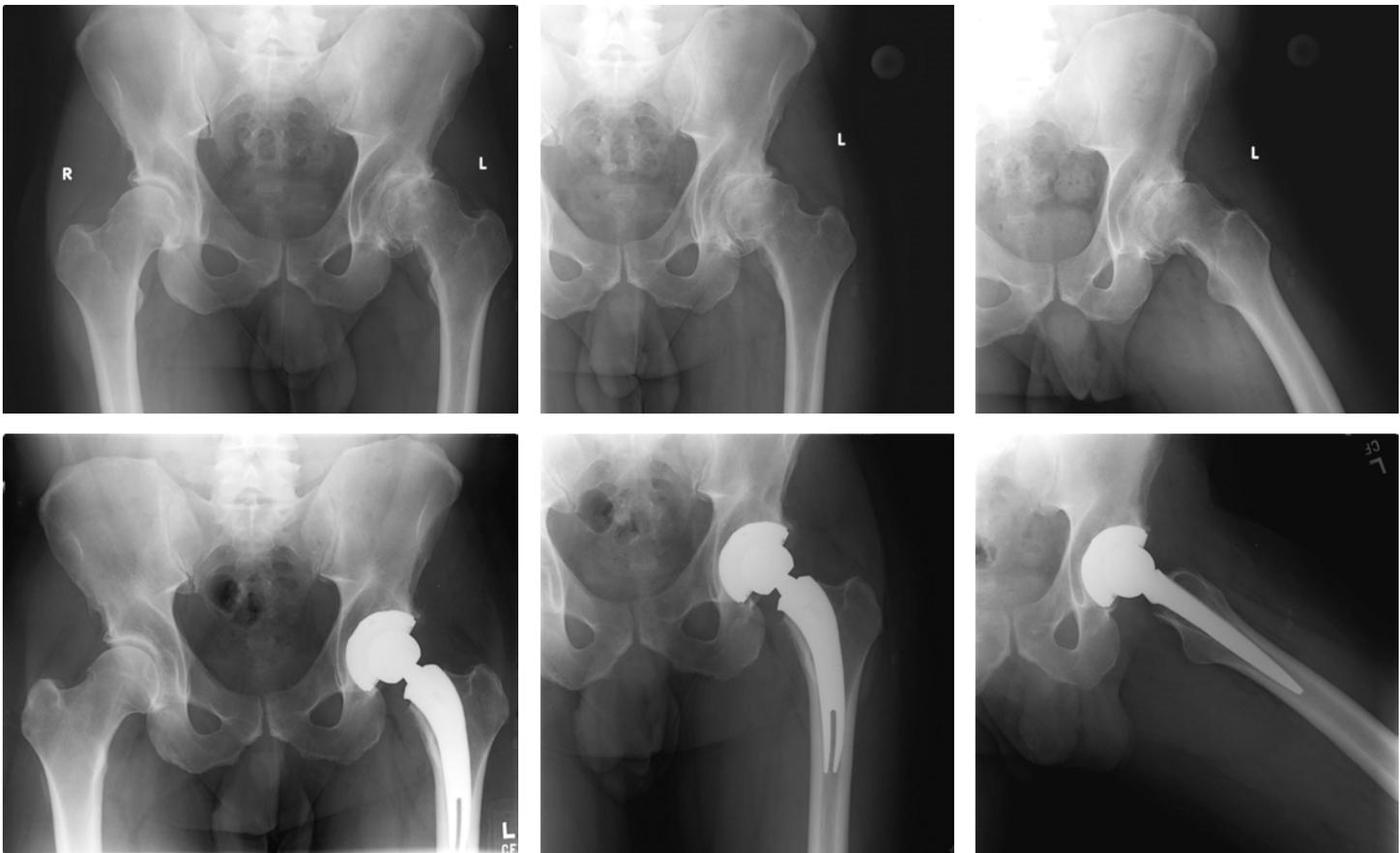
During ambulation, the knee must fully extend during the stance phase or large amounts of energy are needed to keep the body upright. Arthritis frequently results in deformity in the sagittal plane (knee flexion contracture) or in the medial to lateral plane (varus or valgus knee). A knee flexion contracture can cause a limp and concurrent quadriceps atrophy. Notably, in the month following a TKA, quadriceps strength can be reduced by up to 60%, so pre-operative strengthening is critical.⁷ At 6 months, these patients continue to have significant limitations in strength and function compared to healthy matched individuals. A weakened quadriceps muscle can decrease stair climbing ability, gait speed, coordination, and endurance. Both quadriceps neuromuscular electrical stimulation and a progressive resistive strengthening program can improve long-term strength and function.⁷

After a total knee replacement, the expected range of motion is from full extension to 90 degrees of flexion, the minimum required for most activities of daily living. Many patients will achieve 115 degrees of flexion or more.⁸ Most patients who have had a total knee replacement state that the knee did not feel “normal” until roughly a year after surgery. Swelling can persist long after surgery, especially with prolonged activity or ambulation; ice and non-steroidal anti-inflammatory medications can be used as needed during this period. Many patients may also experience “anterior knee pain” or have difficulty kneeling after TKA, which can cause functional limitations and frustration after an otherwise successful operation.

Total Hip Replacement

The hip is a ball-and-socket joint with a functional range of motion less than that of the knee. Prolonged arthritis often leads to hip joint contracture, stiffness, and limited abduction and rotation. Releasing the hip capsule contracture during surgery is often needed for the necessary access to the joint. The diseased capsular tissue is often excised, and a new pseudocapsule will ultimately form around the new prosthetic joint.

In the first three radiographs there is advanced arthritis of the left hip and degeneration of the joint space. After a total hip replacement we can see a well-reconstructed joint. In this instance a “neck-sparing” prosthesis was used, which removes less bone from the femoral neck with the intention of saving bone for future revision if needed.



The most popular approaches to the hip joint include the direct anterior, the antero-lateral, and the posterior approach. Each approach disrupts different muscle planes on the way to the hip joint. Certain exposures are considered “minimally invasive” in that minimal soft tissue is dissected from the bone. Regardless of the surgical approach, all patients must follow certain precautions to reduce the risk of hip dislocation. In the antero-lateral and the posterior approach, the abductor muscles (Gluteus Minimus and Medius) and external rotators are respectfully interrupted and then repaired after the implants are placed. These muscles must be allowed to heal for 6 to 8 weeks, followed by a strengthening regimen. Failure to heal can result in a significant limp.

The direct anterior approach (DAA) is the only truly “muscle sparing” approach to the hip joint. During DAA surgery, the muscles are “parted” between the major nerve groups, and the origin and insertion of the hip flexors, rotators, abductors and adductor groups are completely preserved. This allows the patient to utilize these muscles fully in the immediate postoperative period. A recent randomized study that compared the direct anterior and the anterolateral approaches demonstrated faster functional recovery in the DAA group up to 1 year from surgery. By 2 years, the results were the same.⁹ The long-term results of surgery (10+) years are based largely on the intrinsic durability of the implants and bearing surfaces, and have little to do with the surgical approach chosen at the time of implantation.

As mentioned previously, total hip replacement entails the risk of dislocation. The hip muscles and capsule contribute to joint stability, keeping the femoral head (native or prosthetic) within the acetabulum (or shell). When these muscles are weakened, certain leg positions can result in dislocation of the joint. This depends on the muscle tone of the patient as well as the surgical approach. For instance, hyperextension, adduction, and external rotation should be avoided after a direct anterior or antero-lateral approach. With a posterior approach, the patient should avoid flexion beyond 90 degrees, adduction, and internal rotation. These precautions are most important in the early postoperative period but should be followed permanently. Thankfully, over the past decade the rate of hip dislocations has diminished after THA, due to larger prosthetic femoral head sizes.¹⁰

SUMMARY

Joint replacement surgery remains a dynamic field in orthopedics, and there is an enormous pool of patients whose long-term outcomes can be followed. Countries such as Sweden and Australia have established total joint registries to follow long-term implant performance. Data monitoring has led to worldwide improvements in TJA outcomes. An “American Joint Replacement Registry” is currently being organized on a national level to help follow the outcomes after THA and TKA in this country.

For any joint replacement surgery, patients who are in

better physical condition stand to gain the most function and tend to be the most satisfied. In these elective surgeries, optimizing modifiable risk factors such as glycemic control, weight, and cigarette smoking is critical to obtain a satisfactory result. Successful rehabilitation spans the pre-, peri- and post-operative periods of THA and TKA, so an interdisciplinary partnership between practitioners taking care of each patient is required for a successful outcome.

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Disclosures

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Management of Ankle Fractures

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ABSTRACT

Ankle fractures are a common injury across all age groups. Management may be operative or nonoperative, depending on the severity of the injury and the patient's overall health and functional status. Although imaging defines the nature of the fracture, a careful history and physical also helps determine the patient's plan of care. Initial management is focused on adequate alignment and safe immobilization of the injury. Definitive management must provide anatomic alignment of the joint as well as consideration of the surrounding soft tissues. Rehabilitation after either operative or nonoperative treatment aims at restoring range of motion, strength, proprioception, and function.

KEYWORDS: Ankle, fracture, rehabilitation, treatment

INTRODUCTION

Ankle fractures have increased in incidence over the last 30 years, affecting one in every 800 people each year, typically young active males and geriatric osteoporotic females, and accounting for 9% of all fractures.^{1,2} Management of the fracture itself ranges from nonoperative treatment with immediate weight bearing to surgery and 12 weeks of non-weight

bearing. Care of the patient includes greater considerations such as medical optimization, rehabilitation, and safe return to work and activity.

ANATOMY AND MECHANISM

The ankle is a hinge joint with the tibia and fibula proximally and the talus distally (Figure 1). Ankle fractures classically refer to malleolar injuries: the distal fibula or lateral malleolus, the distal medial tibia or medial malleolus, and the posterior distal tibia or posterior malleolus. Fractures that involve multiple sides are referred to as bimalleolar or trimalleolar. The injury may also involve the deltoid ligament medially or the syndesmotic ligaments laterally. Over 60% of ankle fractures involve only the lateral malleolus.¹ Fractures of the lateral malleolus proximal to the joint line correspond to syndesmotic injuries. The commonly used Weber classification relies solely on the level of the lateral malleolar fracture relative to the ankle joint line.³

The mechanism of injury generally involves a twisting or bending across the joint, whether low-energy as from twisting off a curb or high-energy as from a motor vehicle accident. The most commonly used Lauge-Hansen classification scheme is based on the position of the foot at the time of injury (supination or pronation) and the direction of the deforming force, external rotation, adduction, or abduction.⁴



Figure 1.
Ankle x-ray anatomy:
(A) lateral malleolus,
(B) medial malleolus,
(C) posterior malleolus,
and (D) tibial plafond.

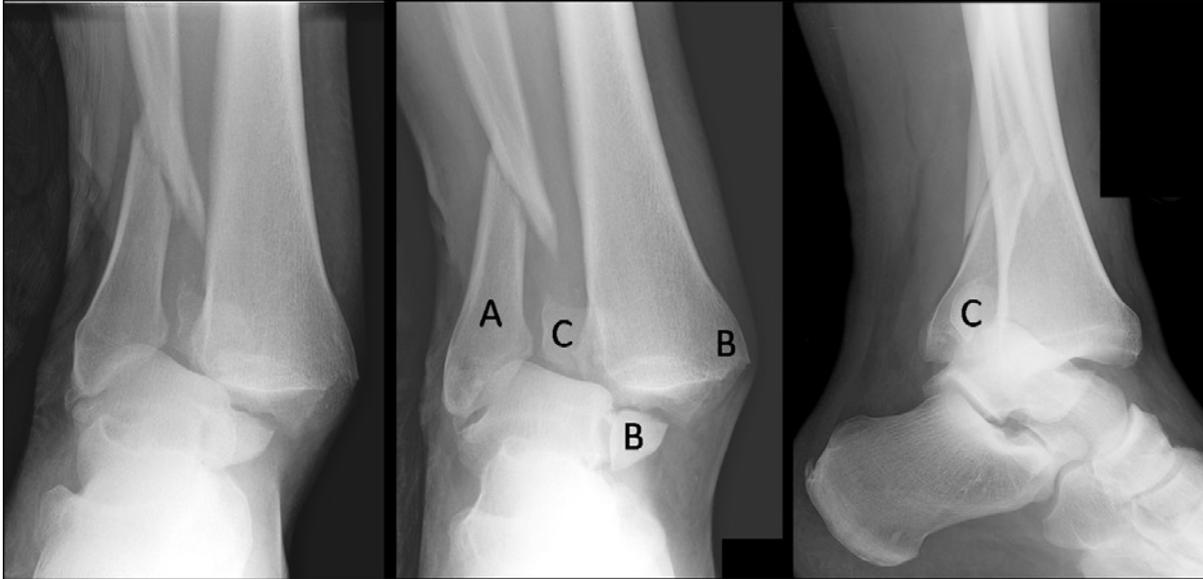


Figure 2. Trimalleolar fracture-dislocation with medial skin tenting by the medial malleolus: (A) lateral malleolus, (B) medial malleolus, and (C) posterior malleolus.

Pilon fractures, caused by an axial load, involve the plafond, the weight-bearing portion of the distal tibia. The management and prognosis of pilon fractures is completely different and will not be covered in the scope of this article.

HISTORY

The general goals of fracture management are anatomic reduction of the fracture and protection of the soft tissue envelope. Stable fractures, where the alignment of the ankle joint is preserved, rarely need surgery. Unstable fractures typically require closed reduction or open reduction and internal fixation, depending on the patient's co-morbidities and pre-injury functional status. There is an increasing trend toward operative management of unstable ankle fractures, but historically good long-term outcomes have been well documented with non-operative management.⁵

Underlying diabetes, nicotine use, peripheral neuropathy, and peripheral vascular disease are all risk factors for poor fracture healing and wound complications.^{6,7} Even without co-morbidities, foot and ankle surgery is notoriously prone to wound dehiscence, deep infection, and nonunion. These complications may lead to repeated operations, prolonged hospitalizations, and intravenous antibiotics. Although non-operative management carries an increased risk of malunion and pressure ulcers from prolonged immobilization, in select populations it is the more prudent approach. Patients whose general health precludes surgery are also candidates for closed reduction and casting as their definitive treatment. However, these same patients may be at increased risk of complications from prolonged limb immobilization and decreased mobility.

Medications that may compromise healing potential such as steroids, chemotherapy, and immune modulators should be noted. Similarly, medications that may cause increased

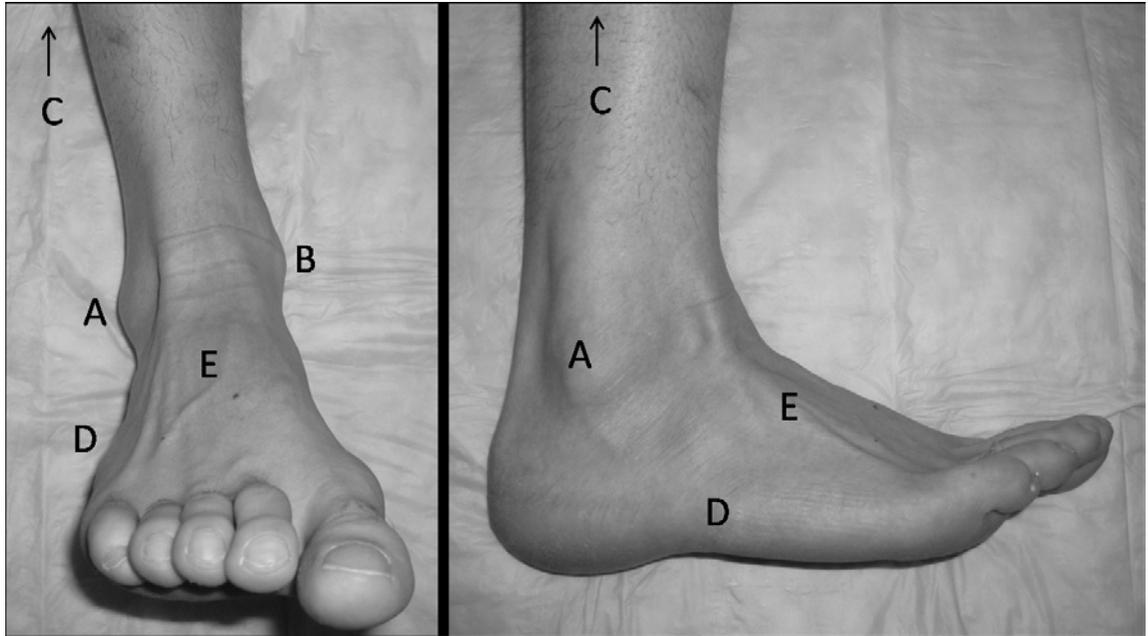
bleeding such as aspirin, warfarin, clopidogrel, and non-steroidal anti-inflammatories should be documented and possibly held preoperatively.

PHYSICAL EXAMINATION

Chronic skin changes related to vascular insufficiency, steroid use, or nicotine use should be documented. Ecchymosis may increase the suspicion of fracture but is usually not present. The degree of swelling, including whether or not skin wrinkles are present, should be noted. In general, swelling may take 24-48 hours to fully develop and 5-7 days to resolve, creating a window when surgery should be avoided. Severe swelling may progress to significant blistering. Any fracture blisters, skin tears, or abrasions over the medial and lateral malleoli should be documented before the ankle is covered and immobilized. Operative fixation, if any, may have to wait until overlying skin heals. In the setting of a fracture-dislocation, the talus most often dislocates laterally and the medial malleolus will tent and even blanch the skin medially, requiring an emergent reduction (Figure 2). Any violation of the dermis or constant bleeding regardless of size should raise concern of an open fracture.

If a fracture is diagnosed by imaging or gross deformity, provocative testing of the ankle should be deferred. Otherwise, when a fracture is suspected, the ankle should be examined using the Ottawa Ankle Rules, which have near 100% sensitivity.⁸ Ankle x-rays for a suspected ankle fracture are only necessary if either one of the following is true: (1) bony tenderness over the posterior edge or tip of the distal 6 cm of the medial or lateral malleoli or (2) inability to bear weight both immediately after injury and at time of examination. These rules should only be applied to the neurologically intact and cooperative patient with no distracting injuries and whose ankle swelling does not prevent palpation of the

Figure 3. Ankle exam surface anatomy: (A) lateral malleolus, (B) medial malleolus, (C) fibula, (D) base of fifth metatarsal, and (E) dorsal midfoot.



bony landmarks. Of note, the ability to ambulate does not exclude an ankle fracture. One of the most common fracture patterns, an isolated fracture of the lateral malleolus with intact medial and syndesmotic ligaments, is a stable injury pattern that allows many patients to ambulate.

The examination should rule out other injuries that may occur with a twisting mechanism. Tenderness just distal to the malleoli or at the base of the fifth metatarsal raises suspicion of a talar avulsion fracture or base of the fifth metatarsal fracture (Figure 3). Swelling and tenderness in the dorsal midfoot may be a sign of a navicular fracture, Lisfranc injury, or other tarsal-metatarsal injury. The entire length of the fibula should be palpated to rule out an associated proximal fracture (Maisonneuve injury). Neurovascular injury is rare but possible: distal sensation to light touch and posterior tibial and deep peroneal pulses should be assessed. Pulses may be difficult to palpate with swelling or underlying vascular disease and should be compared with the contralateral limb or assessed by Doppler. The ability to actively and passively move the toes with minimal pain should be documented. Compartment syndrome of the leg is a rare complication but should be suspected with a high-energy mechanism, significant swelling, inability to actively or passively move the toes, or pain out of proportion to the injury.^{9,10}

IMAGING

To characterize the initial fracture pattern and subsequent maintenance of adequate reduction, imaging should always include anterior-posterior, lateral, and mortise views. While the radiographic thresholds that define an unstable ankle fracture are beyond the scope of this article, for emergent treatment, the talus should be located directly underneath

the plafond of the tibia on all views. With high-energy mechanisms or an unreliable exam, initial studies should include three views of the foot (anterior-posterior, lateral, and lateral oblique), and two views of the tibia/fibula (anterior-posterior and lateral). Computed tomography may identify or better characterize injuries to the plafond and talus. Magnetic resonance imaging is rarely indicated in the acute setting.

INITIAL MANAGEMENT

Fractures with a subluxation of the talus relative to the tibia warrant closed reduction and a well-molded splint to hold the reduction. Intra-articular aspiration of fracture hematoma and injection of local anesthetic are helpful for this painful procedure.¹¹ Even when it is not the definitive treatment, near-anatomic reduction of the fracture decreases damage to the articular cartilage, swelling, soft tissue injury, and pain. Films prior to any manipulation are extremely useful to determine the severity of the injury. However, when the ankle is completely dislocated, the skin is threatened, or there are signs of ischemia, an emergent preliminary reduction without imaging is warranted. Applying axial traction with the knee bent at 90 degrees to relax the Achilles tendon is often sufficient. Restoring the rough alignment of the foot to the leg may save the threatened skin and restore blood flow to the foot. If pulses or Doppler signals do not return after reduction, emergency vascular surgery consultation is warranted.

Open fractures require urgent operative irrigation and debridement with definitive fixation or temporizing external fixation.¹² They should not be left subluxed or dislocated simply because operative intervention is planned. Intravenous first-generation cephalosporins should be started as soon as

the injury is identified.¹² Higher-grade open injuries may also require gentamicin and penicillin. A tetanus booster should be administered if the patient's vaccine is not up to date.

Fractures without subluxation of the talus relative to the tibia still require immobilization for stability, protection of soft tissues, and pain control. A well-padded short-leg posterior splint with side supports is typically used. Isolated, minimally displaced, lateral malleolus fractures may be placed in an Aircast boot for immediate weight bearing but non-weight bearing until follow-up will help reduce pain and swelling. Furthermore, isolated minimally displaced lateral malleolus fractures may have unidentified medial ligamentous injury, creating an unstable fracture. Follow-up x-rays of the ankle stressed in dorsiflexion and external rotation or after the patient has been bearing weight can determine stability. These are decisions that can be deferred until follow-up with the orthopaedic surgeon as there remains no consensus on how to manage these injuries.¹³

Temporary immobilization is not without complication. While immobilization decreases swelling, wrapping a splint too tightly can lead to compartment syndrome. Pressure ulcers of the posterior heel may develop in a matter of hours and are notoriously difficult to manage, so the heel should always be carefully padded. Patients should always be instructed to rest their leg on the calf and not the heel when sitting or lying down. The tendency to leave the ankle plantarflexed or in equinus causes a contracture that may require operative release. Unless not tolerated by the patient, all splints should immobilize the ankle at 90 degrees.

There are no clear guidelines for or against deep venous thrombosis prophylaxis after an ankle fracture. Prophylaxis

should be made on a case-by-case basis based on mobility and other risk factors.¹⁴ Although nicotine use and diabetes are chronic issues that predispose the patient to wound complications, smoking cessation and improved glycemic control even starting at time of injury or surgery may be beneficial.⁶

Patients should follow up with an orthopaedic surgeon in 3–7 days. In the interim, patients should ice and elevate the extremity as much as possible to decrease swelling, which contributes tremendously to pain and can prevent timely surgical intervention. Prompt follow-up care is crucial to avoid turning an operative ankle fracture with a good expected outcome into a crippling injury. Patients should also be advised to seek emergency medical care for increased pain, which may be a sign of resubluxation or compartment syndrome.

Hardware Removal

After the fracture has healed, removal of hardware is indicated only if patients are symptomatic. Some surgeons routinely remove syndesmotic fixation, as they have a tendency to break, loosen, or limit full ankle range of motion. The current literature, however, supports removal only to reduce pain or improve range of motion.¹⁵

REHABILITATION

The goal of rehabilitation is to restore or maintain range of motion, strength, proprioception, and function. Earlier and more aggressive rehabilitation may prevent stiffness and lead to faster recovery as joint motion contributes to cartilage health and non-weight bearing diminishes bone density (Figure 4). Premature rehabilitation, however, may compromise

the anatomic alignment of the fracture. Unfortunately the available literature does not support any specific timing or protocol for rehabilitation.¹⁶

Patients with nonoperative stable ankle fractures are usually in some form of immobilization for approximately 6 weeks. Weight bearing may start immediately or after some initial pain improvement. Exercises for range of motion are started as soon as tolerated.

Patients with unstable ankle fractures that are being treated nonoperatively should expect to be splinted and then casted for 8–12 weeks with weight bearing beginning at approximately 6 weeks. These fractures require close weekly follow up and imaging for at least the first 4 weeks.⁵

Patients with operative ankle

Figure 4. Ankle from figure 2 after open reduction and internal fixation and three months of non-weight bearing to protect syndesmotic fixation (A). There is significant osteopenia demonstrated by increased radiolucency of bone especially on the lateral films as compared to injury films.



fractures are generally immobilized and kept non-weight bearing for 6 weeks. Once sutures are removed at 2 weeks, a removable form of immobilization may be used to allow active and active assisted range-of-motion exercises. If decreased point tenderness and callous formation is present on x-rays at 6 weeks, weight bearing and passive range of motion exercises are begun. In select patients, immediate post-operative weight bearing without immobilization may result in faster rehabilitation with only a slight increased risk of wound complications.^{17,18} Regardless, if the syndesmosis required repair, then weight bearing is usually delayed until 8 or 12 weeks. Generally, patients with diabetes, neuropathy, or who use nicotine are delayed in their weight bearing for 8 to 12 weeks as well.

When weight bearing and range-of-motion exercises are initiated, most patients are stiff from their immobilization but usually do not require formal physical therapy. Patients should advance weight bearing as tolerated but limit activities such as heavy lifting and running.

Patient Expectations

In order to have a successful outcome, patients should understand their injury and comply with their treatment plan. Regardless of how the fracture is managed, patients need to recognize that the ankle will never return to the pre-injury level of function. Even with an ideal fracture reduction, the concomitant damage to the soft tissue and cartilage causes some pain and loss of range of motion.

Patients may return to work as soon as they are able to comply with weight-bearing limitations and immobilization at work, are off narcotic pain medication, and are not a risk to themselves or others. The same rationale applies to driving. For right ankle fractures, braking response time has been shown to be delayed until approximately 9 weeks after surgery.¹⁹

CONCLUSION

Treatment of an ankle fracture involves a careful examination, appropriate imaging, understanding of the fracture pattern, and technically sound fixation or immobilization. Just as important, the patient's treatment and subsequent rehabilitation must be tailored to his or her other medical conditions and pre-injury functional status.

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Disclosures

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Essentials of Anterior Cruciate Ligament Rupture Management

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ABSTRACT

Anterior cruciate ligament (ACL) rupture is a common knee injury and an understanding of current medical knowledge regarding its management is essential. Accurate and prompt diagnosis requires an awareness of injury mechanisms and risk factors, common symptoms and physical/radiologic findings. Early mobilization and physical therapy improves outcomes regardless of treatment modality. Many older patients regain sufficient stability and function after non-operative rehabilitation. Early ACL reconstruction is appropriate for younger patients and those who engage in activities requiring frequent pivoting and rapid direction changes. ACL surgery involves reconstruction of the torn ligament tissue with various replacement graft options, each with advantages and disadvantages. The guidance of a knowledgeable and experienced therapist is required throughout an intensive and prolonged rehabilitation course. Generally excellent outcomes and low complication rates are expected, but treatment does not prevent late osteoarthritis.

KEYWORDS: Anterior Cruciate, Rupture, Non-Operative, Reconstruction, Rehabilitation

I. BACKGROUND

Acute rupture of the anterior cruciate ligament (ACL) is a common cause of knee instability, necessitating over 120,000 ACL reconstructions in the United States annually.¹ An understanding of current diagnostic, treatment and rehabilitation principles is essential in order to care for patients with ACL injuries.

Over two-thirds of ACL tears occur through non-contact mechanisms, including jump landings and knee hyperextension; direct contact from sports and trauma make up the remaining third.¹ Anatomic risk factors for non-contact injury include increased valgus alignment of the lower extremities (knock knees) and characteristic differences in the shape of the distal femur and proximal tibia (e.g. decreased femoral intercondylar notch width). Neuromuscular risk factors include an upright posture (reduced hip/knee flexion) and imbalanced quadriceps – hamstring muscle activation with jump landing activities. A number of these risk factors are present in females, who are significantly more likely to suffer an ACL injury compared with males.²

II. INITIAL EVALUATION AND MANAGEMENT

Patients with an acute ACL rupture state that the knee shifted or gave way during decelerating or changing direction while running. When associated with an audible “pop,” severe pain and immediate swelling (hemarthrosis), the likelihood of ACL tear is 70%.³ Other possible diagnoses for an acute hemarthrosis include patella dislocations/fractures or other osteochondral fractures; effusions associated with isolated meniscal injury typically present more slowly.³ When patients begin to ambulate normally, complaints of instability are common, particularly with pivoting. Mechanical symptoms (i.e. clicking and locking) raise suspicion for concomitant meniscal damage.⁴

During the physical examination, patients should be relaxed in order to prevent quadriceps and muscular guarding. Comparison with the contralateral extremity and a careful neurovascular examination are also crucial for any patient with possible ligamentous knee injury. The ACL is the primary restraint to anterior tibial translation, so its disruption allows abnormal anterior movement of the tibia relative to the femur. The Lachman is the most sensitive test for an ACL tear; with the distal femur stabilized and the knee in 20-30 degrees of flexion, the tibia is pulled anteriorly. Increased laxity compared to the uninjured side and the lack of an end-point indicates a positive test. The anterior drawer test also assesses tibial translation and an end-point, but at 90 degrees of knee flexion.⁴ The pivot shift test is the most specific for ACL rupture, but can be limited by patient guarding. The knee is stressed with valgus and internal rotation forces while simultaneously being ranged from full extension into flexion. With ACL rupture, the anteriorly subluxated tibia will reduce or “pivot shift” back into place as the knee is flexed.⁴ Concomitant collateral ligament injury is evaluated by applying varus/valgus stress at 30 degrees of knee flexion; while posterior cruciate ligament injury is assessed with a posterior drawer maneuver.⁴

Initial imaging includes standard anterior-posterior and lateral plain films. The Segond fracture, a tibial avulsion fracture fragment associated with anterolateral capsule sprain, is pathognomonic for an ACL tear. Tibial spine fractures resulting from ACL avulsion, though rare, are more commonly found in younger patients.⁵ Other possible diagnoses on knee radiographs include subtle findings of patella dislocation and tibial plateau fractures. Magnetic resonance imaging (MRI) demonstrates discontinuity, lack of

visualization, or an abnormal slope of the ACL.⁶ Secondary MRI signs include hemarthrosis, Segond fracture, bone bruising (posterolateral tibia plateau and mid-portion of the lateral femoral condyle), anterior translation of the tibia on the femur, and impaction of the lateral femoral condyle. MRI also aids in the diagnosis of concomitant ligamentous, osteochondral and meniscal injuries (present in 40%-70%).⁵

Initial treatment should focus on decreasing pain, swelling and stiffness. Ice, elevation, compressive wraps and anti-inflammatory medications are recommended.⁷ Bracing in a knee immobilizer and crutches should be avoided beyond a few days and physical therapy should be instituted immediately, even if the knee is painful and swollen. Rehabilitation should encourage range of motion, weight-bearing as tolerated, and progressive isometric strengthening as motion improves. Early rehabilitation enhances the likelihood of success with either operative or non-operative management.⁷ To prevent further joint injury, the patient should avoid high-risk pivoting activities or a return to sports prior to full evaluation and treatment.

III. NON-OPERATIVE TREATMENT AND REHABILITATION

Several studies have classified patient demands and activity levels in an attempt to identify the best candidates for non-operative management (“copers” or “non-copers”). Non-operative treatment is reasonable for patients who can modify their activities and who require less pivoting or quick changes of direction in sports and work.⁷ In one study, 72% of potential “copers” successfully returned to pre-injury activity levels after non-operative treatment without further instability and 43% ultimately avoided ACL reconstruction.⁸

A willingness to attempt non-operative management despite initial concerns regarding knee instability can increase non-operative treatment success, as 60% of potential “copers” and 70% of potential “non-copers” became “true copers” at one year.⁹

Both patient age and willingness to modulate activity are important factors. Over 80% of patients 40-60 years of age at the time of injury had satisfactory outcomes with rehabilitation and activity adaptations; furthermore, they had mild to no radiographic progression of osteoarthritis after an average of seven years. Only a minority (17%) were dissatisfied with their ultimate functional level.¹⁰

ACL-injured patients who function well with non-operative

management can regain dynamic knee stability and return to pre-injury activity levels without ACL support through neuromuscular and proprioceptive re-training.⁸ Common non-operative ACL rehabilitation programs are graduated, initially focusing on progressive strengthening of the quadriceps/hamstring muscle groups and endurance training. Ultimately, increased general agility and sports-specific training is added. The addition of perturbation training, in which subjects learn to compensate for multi-directional movement changes, may further enhance the likelihood of return to baseline activity.¹¹

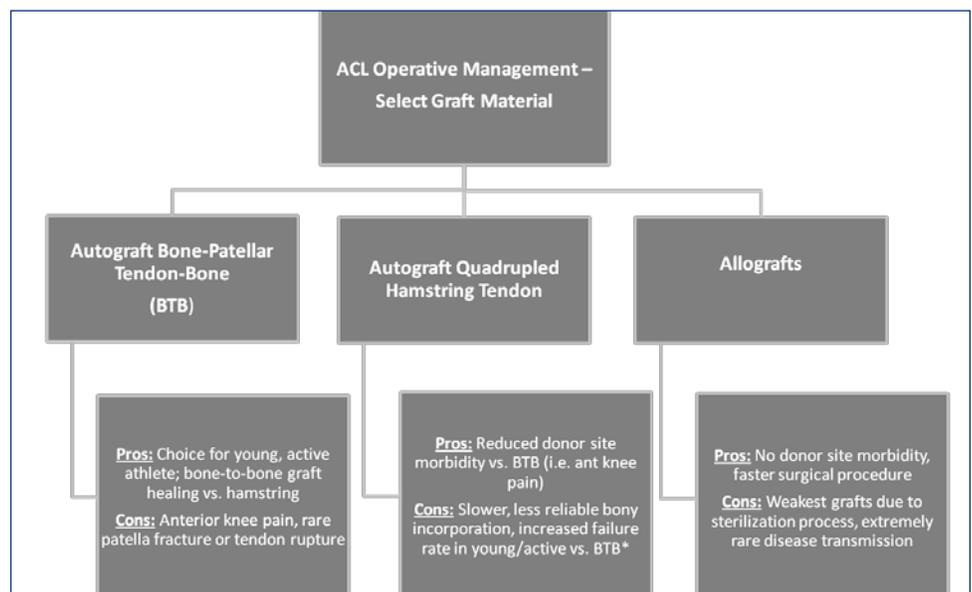
The use of off-the-shelf and custom-fitted ACL braces, though controversial, is encouraged. These braces stabilize the knee by resisting abnormal tibial subluxation and may also improve knee proprioception.¹²

IV. OPERATIVE TREATMENT AND GRAFT SELECTION

Despite rehabilitation after ACL rupture, many patients continue to experience knee instability with activities of daily living, sports or work. Operative management is recommended to restore knee stability and return these patients to their previous level of function.⁷ Current surgical intervention involves arthroscopic reconstruction using either autograft or allograft tendon tissue to replace the torn ACL.¹³ Primary ligament repair historically has poor outcomes,¹⁴ but is currently being revisited using growth hormones and cytokines to help modulate healing.¹⁵

Patients make the decision on graft choice after they research options and discuss alternatives with their surgeon [Figure 1]. Three commonly used graft options include bone-patellar tendon-bone (BTB), quadrupled hamstring, and allografts:

Figure 1. Graft Options for Anterior Cruciate Ligament Reconstruction



Legend: *Barrett, *Am J Sports Med*, 2011¹⁷

BTB Autograft

Often considered the gold standard in ACL reconstruction, BTB autograft requires harvest of the central third of the patellar tendon with attached bone blocks from both the patella and tibial tubercle. Advantages include bone-to-bone healing, ease of harvesting, and good clinical outcomes.¹⁶ Disadvantages include anterior knee pain as well as a low risk of patella fracture and patellar tendon rupture.¹⁶⁻¹⁷ BTB is the graft of choice for more active individuals under 25 years who participate in high-risk pivoting sports. BTB failure rates are less than when hamstring autograft is utilized.¹⁷

Quadrupled Hamstring Autograft

The semitendinosus and gracilis tendons are harvested from their pes anserine attachment and then folded to form a quadrupled construct. This graft has decreased donor site morbidity and greater initial biomechanical strength, which are key advantages compared to BTB. The main disadvantage for the hamstring graft is less reliable healing, because it relies on bone growth into tendinous soft tissue as opposed to bone-to-bone healing.¹⁶

Allografts

Allograft options include cadaveric patellar, quadriceps, hamstring, and Achilles tendons. These grafts eliminate donor site harvest morbidity and have good clinical results in lower demand and revision surgery patients. Despite concerns,

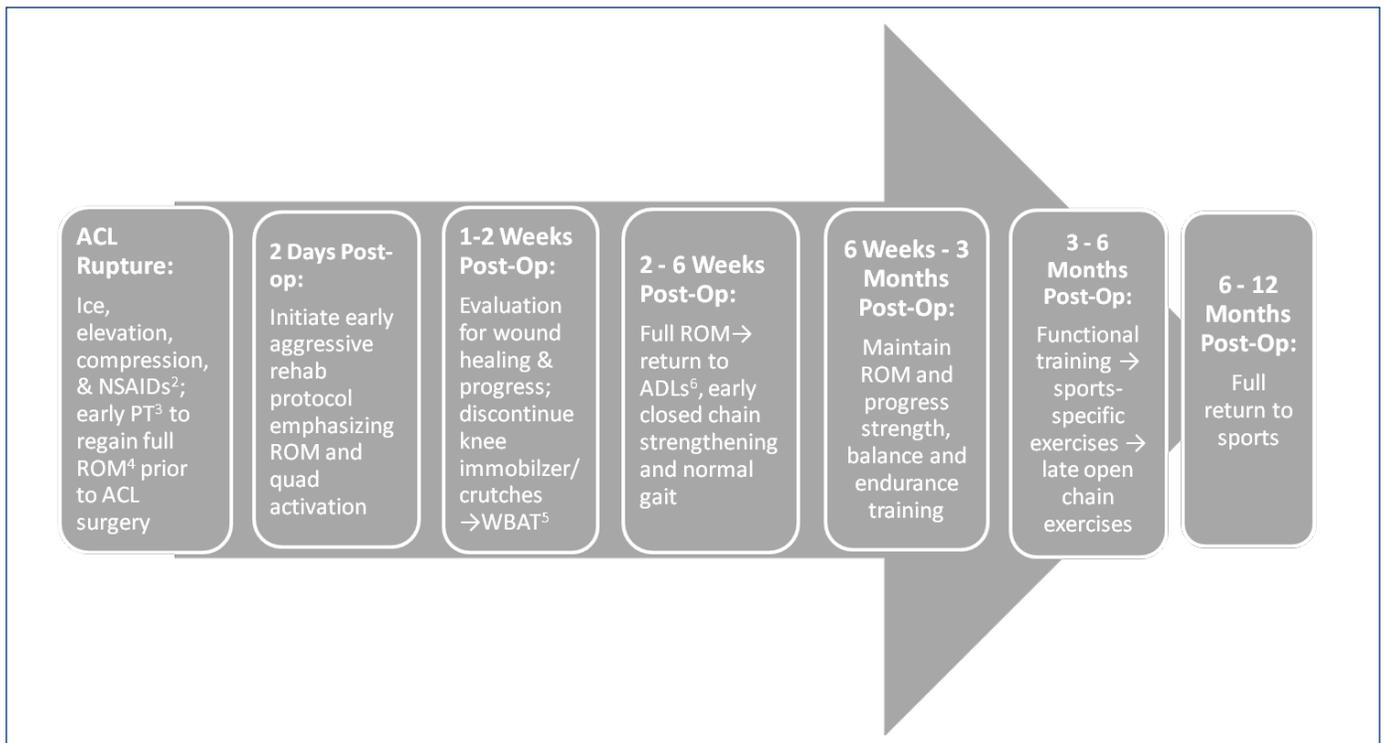
they have extremely low infectious disease transmission rates due to processing and disease testing.¹⁶ Allograft reconstructions have increased failure rates in more active individuals due to graft weakening from sterilization processes.¹⁶

V. OPERATIVE REHABILITATION

Teaming with an experienced physical therapist to guide patients through post-operative rehabilitation is essential for successful outcomes. Rehabilitation after ACL reconstruction should begin within days after surgery [Figure 2]. Key goals are restoration of joint range of motion and strength while protecting the integrity of the surgical graft.¹⁸ Patients are placed in a knee immobilizer and encouraged to begin partial or full weight-bearing with crutches. Range-of-motion exercises begin immediately, with the goal of full extension and flexion to 90 degrees within two weeks. Adjunctive exercises include isometric quadriceps strengthening and patella mobilization.¹⁸ Bracing and crutches are discontinued when there is enough quadriceps strength to allow a straight leg raise without lag. At 10-14 days, the surgeon evaluates wound healing, removes sutures and ensures that initial therapy goals are being met.

During weeks two through six after surgery, therapy should achieve full range of motion, equivalent to the contralateral extremity, through passive and active exercises. Strengthening is gradually advanced after improving range

Figure 2. Anterior Cruciate Ligament Operative Rehabilitation Time-Line¹



Legend: ¹Non-operative rehabilitation follows a similar but shorter progressive course, ²Non-steroidal anti-inflammatory medications, ³Physical therapy, ⁴Range of motion, ⁵Weight bearing as tolerated, ⁶Activities of daily living

of motion. Early routines primarily include closed-chain exercises, in which the foot is in contact with a solid surface (ie, squats or leg presses). These exercises result in effective strengthening (ie, quadriceps and hamstring co-contraction) while minimizing stress on the healing graft, which is most susceptible to failure in this early period.¹⁸

Between six weeks and three months post-operatively, as graft healing proceeds, therapy should maintain range of motion and gradually improve strength and endurance. Stationary biking without resistance and gentle elliptical training are examples of appropriate early endurance activities. After three months, functional training, jogging and swimming are added. Running, plyometrics and sports-specific exercises are added as rehabilitation progresses. Open chain strengthening exercises (eg, knee extensions) place increased stress on the graft and are introduced later. Time frames for therapy advancement should be individualized. For example, sports-specific training should begin only after patients demonstrate 70% strength in the quadriceps and hamstrings compared to the preoperative contralateral extremity. Additionally, patients should regain at least 80% of pre-injury strength before resuming full sports activities.¹⁹ Most patients can return to full sports activity between six and twelve months.¹⁹ Bracing after ACL reconstruction has not been shown to improve outcomes and remains controversial.²⁰

Following surgery and rehabilitation, the majority of patients have normal or near-normal knee function and activity outcome measurements.²¹ Nearly two-thirds of athletes return to pre-injury levels of participation, and almost half resume competitive sports. It is theorized that many athletes do not fully return to prior activity levels despite good knee function because they fear re-injury.²¹ Anterior knee pain (21%-35%) and loss of terminal extension (12%-17%) are the most common complications. Post-operative infections (3%-4%) and graft failures (4%-5%) are infrequent.²² The ACL-injured joint is at high risk for osteoarthritis. The mechanism(s) of cartilage degeneration after ACL tear remain elusive and are most likely multifactorial, including: mechanical factors (eg, kinematics, altered joint loading), biologic factors (eg, inflammation, remodeling), and the presence of associated injuries (eg, subchondral bone bruising, meniscal damage). Current conservative and surgical treatment options do not reduce osteoarthritis following ACL injury.²³

VI. CONCLUSION

ACL rupture is a common knee injury that causes instability and places the joint at risk for late osteoarthritis. A high index of suspicion and thorough history and evaluation of the patient with a "bad knee sprain" will allow a prompt and accurate diagnosis. Early rehabilitation after ACL injury enhances the likelihood of success with either operative or non-operative management, and both options can lead to good patient satisfaction and

outcomes. Patients may function well with non-operative management if they regain sufficient dynamic knee stability with or without modifying their activities. Early ACL reconstruction is appropriate for younger, active patients engaged in activities that require pivoting and rapid direction changes. Surgical treatment requires reconstruction of the ACL with donor tendon tissue, with each graft choice having advantages and disadvantages. Rehabilitation after surgery is intensive and prolonged, requiring the guidance of an experienced therapist. ACL reconstruction restores knee stability with low complication rates and has excellent clinical outcomes, but does not prevent late osteoarthritis.

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Diagnosis and Management of Lisfranc Injuries and Metatarsal Fractures

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ABSTRACT

Forefoot and midfoot injuries are relatively common and can lead to chronic disability, especially if they are not promptly diagnosed and appropriately treated. A focused history and physical examination must be coupled with a thorough review of imaging studies to identify the correct diagnosis. Subtle radiographic changes can represent significant ligamentous Lisfranc injury. Midfoot swelling in the presence of plantar ecchymosis should be considered to be a Lisfranc injury until proven otherwise. While most metatarsal fractures can be treated with some form of immobilization and protected weight-bearing, this article will distinguish these more common injuries from those requiring surgical intervention. We will review relevant anatomy and biomechanics, mechanisms of injury, clinical presentation, imaging studies, and diagnostic techniques and treatment.

KEYWORDS: Lisfranc joint injury, metatarsal fracture

INTRODUCTION

Injuries to the midfoot and forefoot can result from both high- and low-energy trauma and can lead to chronic disability. A thorough history and physical examination as well as careful interpretation of imaging studies are necessary to make the appropriate diagnosis. Plain radiographs are not always diagnostic because of multiple overlapping bones in the foot, particularly on the lateral view. This article will provide an overview of common traumatic foot injuries, focusing on Lisfranc joint injuries and metatarsal fractures. We will review relevant anatomy and biomechanics, mechanisms of injury, clinical presentation, imaging studies, and diagnostic techniques.

LISFRANC INJURIES

Injuries to the Lisfranc, or tarsometatarsal (TMT), joint complex occur in 1 in 55,000 persons each year in the United States, approximately 0.2% of all fractures.¹ Low-energy trauma, including falls from standing and athletic injuries, accounts for approximately one-third of Lisfranc injuries. The remaining two-thirds occur as a result of high-energy trauma (eg, motor vehicle collision, industrial accidents and falls

from heights).^{2,3} Overall, it still remains difficult to quantify the exact incidence of these injuries as nearly 20% are not accurately diagnosed on initial radiographic assessment.⁴

Anatomy and Biomechanics

The forefoot is comprised of five metatarsal bones and the phalanges of each toe. The midfoot consists of five bones: three cuneiforms (medial, middle and lateral), the cuboid, and navicular.

The Lisfranc joint consists of the articulations between the metatarsals and the three cuneiforms and cuboid. Its osseous architecture and soft-tissue connections are critical to the stability of the foot. The Lisfranc articulation can be divided into three longitudinal columns.⁵ The medial column consists of the medial cuneiform and first metatarsal. The middle column is composed of the middle and lateral cuneiforms and the second and third metatarsals. The lateral column is made up of the cuboid and fourth and fifth

Figure 1. Coronal computed tomography (CT) image demonstrating the Roman arch



Med Cun = medial cuneiform
 Mid Cun = middle cuneiform
 Lat Cun = lateral cuneiform
 Cub = cuboid
 5th MT = fifth metatarsal

metatarsals. There is limited motion in the medial and middle column, but the lateral column exhibits significantly more motion. The cuneiforms are trapezoidal, wider dorsally than plantarly, providing stability similar to a “Roman arch” (Figure 1). The second metatarsal is recessed proximally, serving as the “keystone” of the Lisfranc joint.

Soft tissue support of the TMT articulation consists primarily of capsular and ligamentous structures. The Lisfranc ligament is the most important and runs from the plantar medial cuneiform to the base of the second metatarsal. While the second through fifth metatarsals are interconnected by inter-metatarsal ligaments, there is no inter-metatarsal connection between the first and second metatarsals. Thus, the Lisfranc ligament effectively connects the medial column to the lateral four metatarsals. Injury to this ligament can destabilize the entire forefoot as well as the Lisfranc articulation.⁶

Mechanism of Injury

Lisfranc injuries result from both indirect and direct trauma. Direct injuries, including crush injuries and other high-energy mechanisms, are frequently associated with significant soft-tissue trauma, vascular compromise, and compartment syndrome. Therefore, one should have a high suspicion for Lisfranc injuries and these other entities in patients presenting with a history of crush injury to the foot.

There are two common indirect mechanisms of Lisfranc injury: forced external rotation, or twisting of a pronated foot and axial loading of the foot in a fixed equinus position. In a twisting injury, forceful abduction of the forefoot causes dislocation of the second metatarsal and lateral displacement of the lateral metatarsals. This type of injury is in sports involving use of a stirrup, such as at equestrian events. Associated “nutcracker” cuboid fractures can occur due to compression by the fourth and fifth metatarsal bases. Patients presenting with such a cuboid fracture of this nature should be suspected of having an associated Lisfranc injury. Metatarsal base fractures, particularly of the second, are not uncommon with an abduction mechanism.

Axial loading of the foot with the ankle and metatarsophalangeal (MTP) joints in plantarflexion is another mechanism for a Lisfranc injury. Examples include missing a step, catching one’s heel on a curb while stepping down, or force applied when the foot is plantarflexed and the knee is anchored on the ground. The latter usually occurs in American football players when they are kneeling or lying in a prone position and another athlete falls directly onto the heel.^{6,7}

Signs and Symptoms

Patients with Lisfranc injuries tend to present with midfoot swelling and inability to bear weight. Classic findings include forefoot and midfoot edema, and plantar arch ecchymosis, which are considered pathognomonic for Lisfranc injury. Additional findings suggestive of Lisfranc injury include diastasis between the hallux and the second toe on an

Figure 2. Anteroposterior foot x-ray demonstrating Lisfranc injury (the medial border of the second metatarsal does not line up with that of the middle cuneiform)



anteroposterior (AP) foot radiograph – a “positive gap sign.” Tenderness to palpation and inability to bear weight on the tiptoes also suggest injury to the TMT complex.^{6,7}

Stability of the TMT articulation may be assessed with maneuvers such as the “piano key test” (moving the first and second metatarsals into plantarflexion/dorsiflexion and abduction/adduction). Subluxation or discomfort with this test suggests TMT joint injury. The first and second metatarsals should also be stressed divergently.⁸ Of note, stress tests in the acute setting may be limited by patient discomfort and swelling of the foot.

Imaging

An AP view assesses the alignment of the first and second TMT joints, while the oblique view evaluates the other TMT joints; the medial border of the second metatarsal should line up with that of the middle cuneiform. On the 30-degree oblique view, the medial border of the fourth metatarsal should line up with that of the cuboid. Any displacement of these lines is diagnostic for Lisfranc injury (Figure 2). Other signs of Lisfranc injury include avulsion fractures of the second metatarsal base or medial cuneiform (“fleck sign”) and more than 2.7 mm of diastasis between the first and second metatarsals.⁹ Lateral radiographs may reveal dorsal dislocation or subluxation of the TMT joints.⁶

If a Lisfranc injury is suspected despite normal imaging, “stress views” of the foot should be obtained: an AP weight-bearing radiograph with both feet on a single cassette, as well as oblique and lateral weight-bearing radiographs of the injured extremity. One should explain the rationale behind these painful radiographs to improve compliance with equal weight distribution on both feet. The alignment of all columns should be reassessed, and any displacement is diagnostic of TMT joint instability. Diastasis between the first and second TMT joints, if greater than 2 mm compared to the contralateral side, is indicative of ligamentous Lisfranc injury.¹⁰ Lateral weight-bearing films should be examined for loss of arch height and subluxation of TMT joints.

Treatment

Unstable Lisfranc injuries should be treated with either transarticular fixation or arthrodesis, depending on age, degree of underlying arthritis, ligamentous or bony injury, and comminution. Post-operatively, patients are usually placed in a short leg cast for 3 to 4 weeks and then transitioned to a controlled ankle motion (CAM) boot, which allows ankle ROM exercises, for 3 to 5 weeks. Typically, patients do not bear weight for 8 to 12 weeks, depending on surgeon preference and patient symptoms. Patients can be transitioned to a shoe with an orthotic insert at 3 months post-operatively. Physical therapy should be initiated for balance and gait training once the patient’s cast is removed.^{6,7}

Patients with stable injuries can be managed non-operatively and can bear weight as tolerated in a CAM boot for 6 to 10 weeks. After 2 weeks in the boot, weight-bearing images are obtained to monitor for any changes in alignment. A brief course of physical therapy to regain balance, strength, and ROM is recommended. After discontinuing the CAM boot, comfortable, supportive shoes should be worn and some authors also advocate the use of full-length orthotic inserts.⁶

METATARSAL FRACTURES

Forefoot Anatomy and Biomechanics

The forefoot serves two major purposes during gait: (1) the five metatarsals and two sesamoids provide a broad plantar surface for load sharing, and (2) the mobile forefoot allows the metatarsal heads to accommodate uneven ground and maintain even load distribution.¹¹ Displaced metatarsal fractures can disrupt the major weight-bearing complex of the foot. It is critical to correct both displacement in the sagittal plane and excessive shortening of any individual metatarsal. These injuries can result in metatarsalgia due to excessive pressure on one or more metatarsal heads.⁷

Metatarsal Shaft Fractures (Acute Traumatic)

In a study of the epidemiology of metatarsal fractures, 68% were found to involve the fifth metatarsal, most commonly resulting from a torsional mechanism.¹² Metatarsal shaft fractures can also occur from a direct blow to the foot, such

as dropping a heavy object onto the forefoot, causing a transverse or comminuted fracture pattern. In the setting of crush injuries, second, third and/or fourth metatarsals are usually involved.

Patients with acute metatarsal shaft fractures present with pain and swelling of the forefoot, with point tenderness over the fracture site. With multiple metatarsal fractures, a neurovascular exam and soft tissue injury assessment are essential to monitor for foot compartment syndrome.⁷ Radiographic evaluation includes standard, three-view foot x-rays. Weight-bearing x-rays should be obtained if tolerated, to assess the extent of displacement, angulation and shortening on each view. As previously mentioned, fractures at the base of the second metatarsal should raise suspicion for Lisfranc injury.

Treatment

Operative indications for metatarsal shaft fractures include greater than 10 degrees of angulation in the sagittal plane, more than 3 to 4 millimeter translation in any direction, rotational toe malalignment, and shortening that alters the distal parabolic relationship of the metatarsal heads.¹³ These structural changes can lead to metatarsalgia and painful calluses. Transverse plane displacement can lead to interdigital nerve irritation. Additionally, persistent medial or lateral displacement of a 1st or 5th MT shaft fracture can widen the foot and create shoe-wear problems, so they should be reduced and fixed.⁷

Shaft fractures with minimal or no displacement can be treated either in a short-leg walking cast for several weeks or in a hard-soled shoe if comfort allows. The advantage of a hard-soled shoe is that free ROM of the ankle is preserved. Other treatment options include a supportive shoe with a longitudinal arch support to unload the metatarsal heads. Minimally displaced or non-displaced traumatic metatarsal fractures usually heal within 3 weeks and rarely result in functional deficit. Prolonged immobilization should be avoided to prevent joint stiffness.¹⁴

Some fractures of the proximal fifth metatarsal deserve special mention, since their high risk of nonunion makes them unique among metatarsal fractures. These so-called Jones fractures occur at the metaphyseal-diaphyseal junction of the fifth metatarsal, involving the fourth-fifth metatarsal articulation. Due to the poor blood supply in this region, these fractures have a high incidence of nonunion. These fractures are common in athletes involved in contact sports. Management entails strict non-weight-bearing in a short leg cast for 6 to 8 weeks. Due to the likelihood of delayed union or nonunion, Jones fractures often require surgical intervention, particularly in elite athletes. Early surgery minimizes the risk of non-union and expedites return to sports.¹⁵

Metatarsal Stress Fractures (Subacute and Chronic)

Stress fractures of the metatarsal shaft occur as a result of repetitive forefoot stresses, and are commonly seen in athletes; they can also occur after metatarsal-shortening

forefoot procedures that alter the weight-bearing distribution among the metatarsal heads, such as a first metatarsal shortening osteotomy used for hallux valgus (bunion) correction. Stress fractures commonly occur in the second and third metatarsal necks and the fifth metatarsal shaft.¹¹ Patients with high-arched feet are predisposed to stress fractures of the fifth metatarsal since a disproportionate amount of weight is borne on the lateral aspect of the foot.

Patients with metatarsal stress fractures usually have localized pain and tenderness, sometimes without a history of trauma, but often with a recent change in the patient's activity level. The classic finding is tenderness over the affected bone, and hopping on one foot reproduces the pain. A thorough medical history may help to detect secondary causes of stress fractures, such as endocrinopathies, eating disorders, and malabsorption syndromes. A dietary history should address calcium, vitamin D, and protein intake, as well as alcohol and caffeine consumption.¹⁵

Standard three-view weight-bearing radiographs yield results that vary based on the acuity of injury. The earliest findings include subtle radiolucency or poor definition of the cortex; later findings include thickening and sclerosis of the endosteum along with periosteal new bone formation. These later findings may appear weeks to months after the onset of symptoms.^{16,17}

Since radiographic findings tend to lag behind clinical symptoms by weeks, x-rays can be negative, particularly early in the course of disease. In this setting, technetium bone scans and/or MRI can be helpful. Occult stress fractures are generally visible on bone scans days to weeks earlier than on radiographs. While a bone scan has high sensitivity for detecting stress fractures, it is not very specific, and tracer uptake will be seen in the setting of any process that involves bone remodeling, including tumor, infection and stress reaction without fracture.¹⁵ MRI is considered equally sensitive and more specific than a bone scan in diagnosing occult fractures. Diagnostic MRI findings include endosteal marrow edema and periosteal edema in the region of injury.¹⁸

Treatment

Treatment of metatarsal stress fractures involves several weeks of rest and immobilization in a CAM boot, with the duration dependent on tenderness and pain with weight-bearing. A gradual return to previous activity level should begin after the resolution of symptoms. Some institutions also recommend referral to a metabolic bone disease specialist if secondary causes of stress fracture are suspected.¹⁵

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Disclosures

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Nerve Compression Syndromes of the Upper Extremity: Diagnosis, Treatment, and Rehabilitation

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ABSTRACT

Nerve compression syndromes of the upper extremity, including carpal tunnel syndrome, cubital tunnel syndrome, posterior interosseous syndrome and radial tunnel syndrome, are common in the general population. Diagnosis is made based on patient complaint and history as well as specific exam and study findings. Treatment options include various operative and nonoperative modalities, both of which include aspects of hand therapy and rehabilitation.

KEYWORDS: Upper extremity, nerve compression, rehabilitation, carpal tunnel, cubital tunnel

INTRODUCTION

Upper extremity compression syndromes, including carpal tunnel syndrome, cubital tunnel syndrome, and radial tunnel syndrome, are common in the general population. Although they differ in the anatomic distribution of their symptoms, they share a similar pathophysiology and treatment.

As the nerves that control the upper extremity traverse the arm towards the hand, they pass through relatively fixed anatomical structures, or tunnels, usually as the nerve passes a joint. For instance, the carpal tunnel is bounded on three sides by the carpal bones of the wrist and on the fourth by the transverse carpal ligament; it marks the transition from the forearm to the hand. These tunnels are unable to accommodate swelling, which can occur due to renal failure, diabetes, thyroid disease, rheumatoid arthritis, and alcoholism; fractures at the site of the tunnel; and conditions involving physiologic fluid shifts, including pregnancy; most swelling, however, is idiopathic.¹ When swelling occurs within the limited volume of the tunnel, the nerve is compressed, which compromises the microvascular blood supply and leads to focal ischemia of the nerve. This in turn leads to demyelination, which disrupts nerve signal transmission; prolonged compression can lead to more permanent damage to the neurons themselves, including degeneration distal to the point of compression. The inflammation and ischemia also leads to fibrosis, which can further tether the nerve and lead to more traction injury during motion. This pathophysiologic process is experienced by the patient as pain, paresthesias, loss of sensation, and muscle weakness in the distri-

bution of the affected nerve. It is important to note that the presentation of cervical radiculopathy resembles that of peripheral nerve compression, and care must be taken to make the correct diagnosis. In some cases, the peripheral nervous system is compromised in both areas, a condition known as the double crush syndrome,² which also complicates the diagnosis and treatment.

Carpal Tunnel Syndrome

Carpal tunnel syndrome (CTS) is the most common nerve compression syndrome of the upper extremity, with an incidence of 3% to 5% in the general population.³ It is caused by compression of the median nerve as it crosses through the fibroosseous carpal tunnel at the wrist, along with the nine extrinsic flexor tendons. Most cases are idiopathic and work related, with a significantly proportion coming from occupations that involve manual force, repetition, and vibratory tools.⁴

Symptoms include loss of sensation and paresthesias in the distribution of the median nerve (thumb, index finger, middle finger, and radial half of the ring finger); a weak grip, clumsiness, and hand pain that awakens the patient at night. The clinical examination may reveal thenar atrophy, decreased sensation, and positive responses to provocative tests, including Phalen's, Durkan's, and Tinel's (Figure 1). Decreased two-point discrimination may be more prevalent in the advanced stages of the disease.⁵ Electrodiagnostic testing also has typical findings including increased motor and sensory latencies and decreased conduction velocities across the carpal tunnel.¹ Electromyography reveals signs of denervation, such as fibrillations and positive sharp waves.

Conservative management of CTS begins with splinting, as multiple studies have shown improvement with both night splints and full-time splints.⁶ Other studies have shown benefits from ultrasound treatments, yoga, and carpal bone mobilization.⁷ Corticosteroid injections into the tunnel also provide symptomatic relief; 20% of patients remain symptom-free at one year. Steroid injections may also help make the diagnosis if it remains unclear, and can serve as a useful prognostic tool, as patients that experience no initial relief after injection may not experience symptomatic relief with surgery.¹

Surgery is usually successful in treating CTS, with a 90% success rate.⁸ All surgical techniques divide the transverse carpal ligament, release the volar border of the carpal tunnel,

Figure 1. Provocative testing in Carpal Tunnel Syndrome (a) Phalen's test, wrist hyperflexion; (b) Durkan's test, direct compression of the median nerve; (c) Tinel's sign, tapping over the course of the nerve elicits paresthesias



and decompress the nerve in the carpal tunnel. Endoscopic techniques have a faster recovery time and higher patient satisfaction within the first several weeks when compared to traditional open approaches, but these differences are undetectable at one year of follow-up.⁸

Cubital Tunnel Syndrome

Cubital tunnel syndrome (CuTS) is the second most common nerve compression syndrome, affecting roughly 25 out of every 100,000 people.⁹ It is caused by compression of the ulnar nerve as it crosses the elbow. The cubital tunnel is formed by Osborne's ligament and the medial collateral ligament of the elbow, but the ulnar nerve passes through other structures around the elbow, each a potential site of nerve compression: the arcade of Struthers, the medial intermuscular septum, the medial head of the triceps, the anconeus epitrochlearis, the two heads of the flexor carpi ulnaris (FCU), and the proximal edge of the flexor digitorum superficialis.¹

Patients present with numbness and paresthesias in the distribution of the ulnar nerve (the small finger and ulnar half of the ring finger); they also experience weakness of the intrinsic hand muscles (interossei, medial lumbricals), but rarely have pain.¹⁰ Advanced disease is accompanied by atrophy and progressive weakness, giving rise to a host of eponymous hand deformities, including Duchenne's sign and Wartenburg's sign (Figure 2).¹¹

As in carpal tunnel syndrome, the examination includes

many provocative maneuvers that reproduce the patient's symptoms. These include a Tinel's sign (tapping over the nerve at the elbow) and the elbow flexion test (in which the wrist is also extended, putting the ulnar nerve on maximum stretch).¹² Electrodiagnostic testing is less reliable in cubital tunnel syndrome, as the nerve compression is more intermittent than in carpal tunnel.¹³

Conservative treatment of CuTS consists of splinting the elbow in minimal flexion to take tension off the nerve, along with activity modification. Corticosteroid injections, nerve gliding, and ultrasound treatments are controversial.¹³

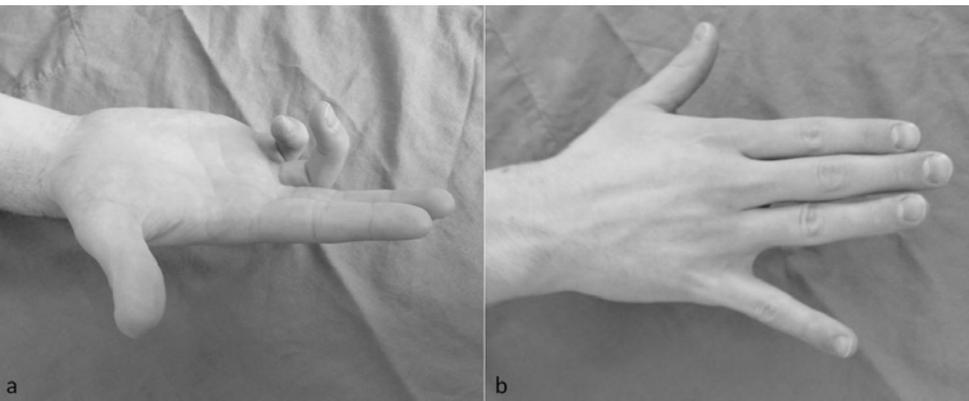
There are two surgical techniques used in the treatment of cubital tunnel syndrome. In situ decompression involves releasing the structures overlying the nerve, with the nerve left in place. With decompression and transposition, the ulnar nerve is moved anterior to the medial epicondyle. In theory, this leads to less stretching of the nerve during elbow flexion; however, studies have failed to show a significant difference in outcomes between the two techniques.¹⁴

Posterior Interosseous Nerve Compression

Radial Tunnel Syndrome (RTS) and Posterior Interosseous Syndrome (PIS) both refer to compression of the posterior interosseous nerve (PIN). The PIN branches from the radial nerve three to five centimeters distal to the lateral epicondyle; the nerve then dives under the arcade of Frohse (proximal edge of the supinator) and into the radial tunnel, consisting of the radiocapitellar capsule, supinator, and extensor carpi radialis brevis (ECRB). The vascular Leash of Henry, which is composed of branches of the recurrent radial artery, is yet another potential sites of compression of the PIN.^{1,15} It is important to note that while the PIN does have afferent fibers that transmit pain signals from the wrist, it does not carry any cutaneous sensory information, which can help distinguish a PIN palsy from cervical radiculopathy.

RTS is a controversial diagnosis, with some doubting its very existence. It is typified by point tenderness over the mobile extensor wad, without motor or sensory symptoms, and without any findings on

Figure 2. Hand deformities resulting from ulnar nerve injury (a) Duchenne's sign, clawing of the two ulnar digits resulting from loss of interossei and ulnar lumbricals; (b) Wartenburg's sign, increased passive abduction of small finger



electrodiagnostic testing. Pain can sometime be elicited by resisted forearm supination or resisted middle finger extension, but these provocative tests are not well established.¹⁶ The posterior interosseous syndrome (PIS), on the other hand, is a more conventional compression syndrome; it causes weakness in the distribution of the PIN and may yield abnormal electrodiagnostic findings.

Treatment for both syndromes is similar, beginning with splints, nonsteroidal drugs and activity modification; progressing to corticosteroid injections; and finally requiring surgical release of the proximal PIN for refractory cases. Patients with PIN syndrome tend to undergo surgical release earlier, partially because its motor symptoms lead to an easier diagnosis. Studies show generally good outcomes after release for PIN syndrome, with better outcomes for earlier releases.¹⁷ Surgical release for RTS has poorer outcomes; much of this may be due to poor patient selection in view of the difficulty in making the diagnosis.¹⁸

Rehabilitation

Occupational therapy plays an important role in the management of upper extremity nerve compression syndromes. Skillful hand therapy may help avoid surgery altogether. Conservative management includes activity modification as well as splinting the affected nerve. For patients who undergo surgical treatment, hand therapy is crucial in postoperative rehabilitation for appropriate return to normal function.

After surgery for any of the above syndromes, the basic principles of rehabilitation remain the same. Surgeries that involve any period of postoperative splint or sling immobilization of a joint (i.e, the elbow in cubital and radial tunnel releases) require therapy for range of motion. Many nerve compression syndromes have some element of weakness or atrophy preoperatively; therapy should therefore also focus on strengthening.¹⁹

Scar massage can help with collagen remodeling and with desensitization; similarly, nerve-gliding exercises are employed to prevent fibrotic adhesions from reforming around the released nerves.

CONCLUSION

Nerve compression syndromes of the upper extremity are common afflictions. The diagnosis can usually be made with a careful history and physical examination, but supplemental diagnostic studies can be useful. Conservative treatment often suffices; for refractory cases, surgical release is usually definitive. Therapists play an important role both in initial management as well as postoperative rehabilitation.

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