

In this paper I will discuss the anatomy of the lower extremity as it relates to the hip, thigh, knee, ankle and foot regions in terms of the following components: tendon, bone, articular cartilage, ligament, muscle, and nerve. I will at the same time be covering the most common injuries seen in runners and discuss differential diagnosis for these injuries. It is out of the scope of this paper to discuss treatment options in physical therapy for the covered injuries.

The reason I chose to address this topic, is that the number of runners currently participating in sport is increasing every year. A survey of sports participation in 2003 found that 36 million Americans ran at least once in that year, 10.5 million ran  $\geq 100$  days and 12 million have been in the sport for  $\geq 10$  years. (1) Unfortunately with all of the new individuals that are taking to running and even those that have been running but may be sporadic in their training, injuries are also on a rise and are being seen more often in the physical therapy clinic.

### **Overview of the Anatomy of the Lower Extremity:**

I will start with an overview of the regions of the lower extremity that are most commonly injured in the running population and then will become more specific as to the tissues and structures that are affected and the common diagnoses seen in those areas.

#### **The Hip:**

Approximately 10% of athletes who seek care at sports medicine clinics report chronic hip pain. (2, 3, 4) The hip region is the area between the iliac crest and the greater trochanter of the femur, lateral and including the hip joint. (5) The “hip bone” is formed by three bones: ilium, ischium, and pubis and the three bones that are originally separated by cartilage, fuse together by the age of 23 years old to create the cup shaped socket also known as the acetabulum. (5) The acetabulum allows for articulation with the head of the femur bone, which forms the thigh region, to create the hip joint. (5) The hip joint is classified as an enarthrosis or ball and socket joint.

Hip injuries are caused by either intrinsic or extrinsic factors. While it is believed that most injuries at the hip are a result of complex interactions among various factors the intrinsic factors can include: high degrees of hip external rotation and narrow tibial bone width; leg length discrepancies of >10-15 mm; previous injury and/or incomplete rehabilitation of a previous injury; regional muscle strength imbalance; and obesity which increases peak forces at the hip joint while running. (6, 7, 8, 9, 10)

The extrinsic factors can include: improper running technique or inexperience; worn out or improper footwear; poor running surfaces; abrupt changes in running routines; inadequate nutrition or hydration; and excessive mileage (>40 miles a week) or competitive running. (11, 12, 13)

Hip injuries can also be classified as overuse or traumatic as well. The overuse injuries caused by running can be broken down into intrinsic and extrinsic factors. Included in the intrinsic factors are: malalignment of the lower extremity, muscle imbalance, muscle weakness, lack of muscle and joint flexibility, sex, body size, and leg length discrepancy. The extrinsic factors include: training errors, running surfaces, shoes, environmental conditions, psychological factors and inadequate nutrition. (14)

### **The Knee:**

The knee is the most common site of overuse injury in runners. (15) The knee joint is classified as a hinge type of synovial joint that permits some rotation. There are three articulations: an intermediate one between the patella and the femur and medial and lateral ones between the femoral and tibial condyles. (5)

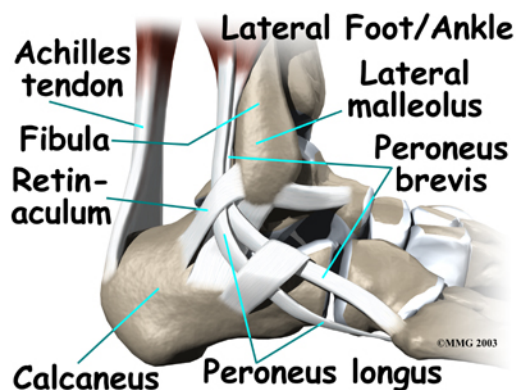
The bones that make up the knee joint are the femur, tibia and patella. The articular surfaces are the large curved condyles of the femur, the flattened condyles of the tibia and the facets of the patella. When an individual stands in the anatomical position, the knees are in contact, but the femora are set obliquely because their heads are separated by the

width of the pelvis. This produces an open angle at the lateral side of the knee, toward which the patella tends to be displaced when the quadriceps femoris muscle contracts. (5)

The knee joint is relatively weak mechanically because of the configurations of its articular surfaces. It relies on the ligaments that bind the femur to the tibia for strength. The principle movements occurring at this joint are flexion and extension of the leg, however some rotation does occur in the flexed position. The knee joint is made up of ligaments, bursa, tendons, synovial membrane, and menisci.

### **The Ankle:**

Ankle injuries account for almost 15% of all sports injuries. (16) The ankle complex is made up of two joints: the talocrural joint and the distal tibiofibular joint. (Figure 1) The talocrural joint is a hinged synovial joint that is located between the distal tibia and fibula and the superior portion of the talus. The distal tibiofibular joint is a syndesmosis (fibrous joint) which is made up of a strong interosseous ligament and two smaller ligaments (anterior and posterior tibiofibular). (16) Ankle injuries are typically classified as either overuse injuries or traumatic injuries.



**Figure 1: The Ankle Joint (lateral view)**

[www.eorthopod.com/images/contentimages/ankle](http://www.eorthopod.com/images/contentimages/ankle) (accessed 12/7/06)

### **The Foot:**

Between 10% and 20% of all running injuries are foot injuries and because of this foot problems are the most common injuries that are reported by long distance runners. (17, 18)

During running, the stance phase of gait changes from about 60% of the gait cycle to as little as 30%. During this shortened stance phase there is increased demands on the foot because it must change rapidly from a rigid structure at initial contact with the ground to prevent buckling of the knee, to the planted foot which needs to be flexible to accommodate uneven surfaces and allow the forces to be dispersed over a broader surface area, and then back to a rigid structure to transfer forces during push off. (19)

The foot is divided into three distinct regions: 1) the rearfoot, 2) the midfoot, and 3) the forefoot. The rearfoot consists of the calcaneus and talus and also related soft tissue structures. The midfoot consists of the cuneiforms, the navicular, and the cuboid along with related soft tissue structures. And finally the forefoot consists of the metatarsals and phalanges. (20)

### **Tendon:**

Tendon tissue composition is made up of three primary components: cells, fibers, and ground substance. Fibers and ground substance are often referred to as extracellular matrix. In tendon the fibroblast cells account for roughly 20% of the tissue volume with the remainder being extracellular matrix (70% of which is water). (21) Collagen is the primary fiber component in tendon and is also the primary solid component in the extracellular matrix. Nearly all tendon fibrils are oriented longitudinally and are oriented along the line of tensile stress. Because of its relative stiffness tendon does not change appreciably in length in response to tensile loading. (21) Tendon also undergoes a continual process of resorption and repair and exercise and disuse are two stimuli that will alter this balance. (21)

In general the vascular supply of tendon is sparse and some regions are almost avascular. (21) The vascular supply is provided through three primary routes: vessels entering at tendon insertion sites, vessels entering at the tendon-muscle interface, and mid substance vessels from adjacent soft tissues. (21)

The function of tendon is as a transmitter of force produced by contractile and noncontractile elements within the muscle-tendon unit. (21) Tendons follow a course from their origin to their insertion via three different pathways: directly, around a bony pulley (ex: tibialis posterior muscle), or by passing around a retinacular structure (ex: tibialis anterior muscle). (21)

In order to understand how injury of tendons occurs it is important to discuss the concepts of stress and strain in relation to tendons. The magnitude of loading is described as stress. Strain is defined as the deformation that develops within a structure in response to an externally applied load. To calculate stress you take the magnitude of the externally applied load and divide by the cross sectional area of the tissue being tested. (21) The tensile stress is calculated by dividing tensile load by the cross sectional area that is perpendicular to the direction of tensile loading. (21) Tendon in general becomes stiffer as loading continues. When mapping this relationship out on a stress-strain curve, the curve almost becomes linear as loading continues and this correlates to the straightening out of the collagen fibers in response to the load. (21) As loading continues eventually it will reach a point of maximum load or ultimate strength. Tendon undergoes rapid failure after continued loading past the ultimate strength. Cyclic loading within normal physiological limits can also lead to greater deformation of the tendon and microfailure of the tissue over time. (21) The ultimate strength of tendon is approximately four times the maximum isometric tension that can be generated by the tendon's muscle. (21)

Tensile stress is one possible mechanism of injury for tendon, the myotendinous junction, and the tendon's insertion into bone. (21) Tensile stress may result in a shearing force and ultimately failure in the tendon. Tendon is also vulnerable to compression against both a bony pulley and retinacular pulley, and even external factors such as pressure from tight

shoelaces as well. (21) As these compressive forces increase so does the tension in the myotendinous unit and the friction between the tendon and the surrounding soft tissues. This tension is often capable of inducing pathological changes in the tendon structure. (21) Other factors such as frequency of loading, age of the person, vascularity and some drugs can affect the ultimate strength of tendon and cause pathology as well. (21)

Healing of tendon occurs in three phases: inflammation, proliferation, and remodeling. To describe in detail these phases is beyond the scope of this paper, however the inflammatory phase typically lasts 3 days after acute injury, the proliferation phase can last up to 4 weeks and if the tendon and muscle unit are subjected to physiological loading remodeling will occur optimally and in general optimal realignment occurs within the first two months. (21) Also of note is that healing tendon tissue is weaker than uninjured tissue secondary to tissue defects and poorly aligned and immature collagen fibrils. (21) This is important because the optimal physiological loading has not taken place during the healing process or if an athlete attempts to return to sport too quickly after an injury the risk of re-injury is greater. (21)

### **Iliotibial Band Syndrome:**

The iliotibial band (ITB) is a strong tendinous continuation of the tensor fasciae latae and gluteus maximus muscle that originates near the iliac crest and inserts on the lateral tibia (Gerdy's tubercle), fibular head and lateral patellar retinaculum. At its tibial insertion the ITB blends with the fibrous expansions of the biceps femoris and lateral quadriceps muscles. (22) Injury to the ITB is the most common cause of lateral knee pain in runners, but may also generate lateral hip pain as well. (22)

The syndrome results from repetitive friction of the ITB sliding over the lateral femoral epicondyle. The ITB moves anterior to the epicondyle as the knee extends and posterior as the knee flexes, remaining tense in both positions. (23)

Biomechanical studies of runners with ITB syndrome show that in the running cycle, the posterior edge of the ITB impinges against the lateral femoral epicondyle of the femur just after foot strike. This “impingement zone” occurs at, or at slightly less than, 30 degrees of knee flexion. (24)

Irritation of the ITB is likely multifactorial, but excessive or sudden mileage increases, little running experience, leg length discrepancies, genu varum, cavus feet, regional muscle weakness, banked running surfaces, inappropriate footwear, hip inflexibility and shorter statures are most often implicated. (22, 25)

Symptomatically, ITB syndrome is characterized by sharp or burning pain along the lateral hip, thigh or knee that worsens with activity. (26) The pain initially subsides after running, however progresses to occur during light activity and even rest. Hill climbing and or stairs particularly exacerbate symptoms. (27) Runners with ITB syndrome have also been found to be weaker in knee flexion and knee extension, with decreased maximal braking forces. (22)

Severe lateral knee pain associated with ITB syndrome may be intensified by myofascial restrictions that are directly or indirectly associated with the excessive friction of the ITB sliding over the lateral femoral epicondyle. (24) Myofascial restrictions include central and attachment trigger points, muscle contractures, and fascial adhesions. These restrictions may contribute to excessive tension on the ITB may precede and accompany the condition, or may linger after the primary friction syndrome has subsided. Evaluation often reveals tender areas in the vastus lateralis muscle, gluteus minimus muscle, piriformis muscle, and distal biceps femoris muscle. Within these tender areas, discrete trigger points are often found that can refer pain to the lateral thigh, the knee, or even the lateral lower leg. Examination should consist of thorough and firm palpation of the trigger points and this is best performed while the individual is resting comfortably on their side with the affected limb hip flexed to about 45 degrees and knee flexed slightly on a bolster. (24)

Hip abductor strength deficits are often noted in the affected leg. Ober's test, Noble Compression and also the modified Thomas test (see special tests section) may both be positive. Since ITB syndrome is a clinical diagnosis, diagnostic testing typically only serves the purpose of excluding other potential conditions. (28)

Of interest in regards to the ITB there is also much debate in the literature as to what structure lies underneath the ITB. At least one study has shown "potential space" under the ITB and suggests that the cystic abnormalities sometimes seen with MRI represent a bursa. (29) However, there are more than enough other studies that refute the findings of a bursa beneath the ITB (30) and one study concluded that the synovial tissue present under the ITB has a capsular origin. (31) The general consensus seems to be that there are anatomic variations among individuals who develop ITB syndrome. (32)

### **Achilles Tendonitis:**

The Achilles tendon is the largest tendon in the body and is composed of fibers from the gastrocnemius muscle and the soleus muscle that combine and insert on the calcaneal tuberosity. The tendon has no true synovial sheath and is instead covered over its entire length by a paratenon. (33)

Achilles tendonitis is a very common complaint in runners. A study by Barr et al. found that the odds of a runner developing Achilles problems was 10 times greater than in age-adjusted controls. (16) In general the training history of the patient will show excessive mileage, sudden increases in intensity, inadequate warm up and stretching, and or muscle imbalances. The most common tender area to palpation in this region is 2 cm to 6 cm (zone of relative avascularity) above the calcaneal insertion. The physical examination will also include: sensitivity of the tendon to palpation, a painful or swollen area that moves with dorsiflexion and plantarflexion of the foot (Arc Sign), and pain that decreases or disappears completely with maximum dorsiflexion (Royal London Hospital Test). (16) Retrocalcaneal bursitis can often time mimic Achilles tendinosis, but the pain is generally localized more inferiorly. (16)

Running can exert forces up to six times a person's body weight on the tendon with each step. In a person already limited with tendinosis or partial rupture, if activity is not monitored or limited, complete rupture could occur. (33) Achilles tendon rupture occurs predominantly in men between the ages of 30 and 40 and 75% of these ruptures occur in athletes. (34)

The causes of Achilles tendon rupture are not always clear however theories such as repetitive microtrauma, inhibitor mechanism malfunction, a correlation of rupture with blood type O, hypoxic and mucoid degeneration, and decreased perfusion that results in degenerative changes and systemic or locally infiltrated corticosteroids. (34)

A Thompson's test in which the patient lies prone with the calf relaxed while the examiner squeezes the calf musculature, is positive (indicative of a rupture) if there is no movement at the foot into plantarflexion. (16) MRI and ultrasound would also confirm this diagnosis as well.

### **Posterior Tibial Tendonitis:**

Posterior tibial tendonitis symptoms present as medial ankle pain. The tendon passes posterior to the medial malleolus and inserts on the navicular bone. This is a common overuse injury and is typically seen with rapid increases in training intensity or poor footwear because of eccentric forces that occur as the muscle resists descent of the medial longitudinal arch. Runners will present with pain along the tendon and with resisted foot inversion. Physical exam may demonstrate excessive pronation and a tight posterior tibialis muscle. (16)

### **Anterior Tibialis Tendonitis:**

The most common cause of anterior ankle pain in runners is anterior tibialis tendonitis. This injury is caused from overuse and typically from sudden increase in training

frequency and duration. Other causes are rear foot strike pattern and shoe posterior heel flare. Physical examination shows tenderness and swelling over the tendon and pain with resisted dorsiflexion. (16)

### **Peroneal Tendinopathy:**

Peroneal Tendinopathy is another common overuse injury cause of lateral ankle pain and should be considered especially if the patient's history shows no ankle sprains. Generally believed to be caused from excessive pronation and dorsiflexion of the foot, physical examination will reveal tenderness over the tendon and pain with resisted dorsiflexion. (16)

### **Extensor and Flexor Tendonitis:**

Forefoot tendonitis, especially extensor tendonitis, is common in runners. Running hills is believed to be a risk factor because of the increased toe dorsiflexion range of motion needed when running uphill and the increased and prolonged eccentric contraction when running downhill. (35)

### **Bursa:**

Bursae are fluid filled sacs that provide cushioning between bony prominences and the surrounding soft tissues. Bursal inflammation (bursitis) may result from chronic microtrauma, arthritis, regional muscle dysfunction, overuse, or acute injury. (36, 37, 38)

### **Hip:**

There are at least 13 different bursae present in the hip and groin region however most runners will develop symptoms only in the trochanteric, ischial and iliopectineal bursae. (39)

The trochanteric bursa is the most commonly affected hip bursa and overlies the lateral aspect of the greater femoral trochanter where it provides cushioning for the gluteus tendons, iliotibial band, and tensor fascia latae. (36) The trochanteric bursa is also composed of subgluteus minimus, maximus, and medius components and therefore bursitis in this region is often times referred to as greater trochanteric pain syndrome because inflammatory findings of erythema, edema, and warmth are uncommon. (36)

Greater trochanter pain syndrome generally affects women 4 times as often as men and peaks between the fourth and sixth decades of life. (36) Factors such as gluteus medius insertional dysfunction, hip osteoarthritis, lumbar spondylosis, excessive or rapidly increased running mileage, frequent training on hard or banked running surfaces, poorly cushioned shoes, excessive pronation, leg length discrepancies, and iliotibial band syndrome can all contribute. (36)

Individuals presenting with greater trochanter pain syndrome typically will report persistent lateral hip pain that worsens when lying on the affected side, tenderness along the posterior aspect of the greater trochanter, difficulty when climbing stairs, and or pain when transferring from supine to standing. (36) Pain may also radiate down the medial thigh mimicking lumbar disc herniation (pseudoradiculopathy). (36) Physical examination will find diffuse or localized pain over the greater trochanter and often time's pain may be reproduced with abduction and external rotation of the involved side. (37)

The iliopectineal bursa underlies the iliopsoas muscle where it passes over the femoral head and inserts onto the lesser femoral trochanter. Chronic rubbing of the iliopsoas tendon on the iliopectineal bursa during sprinting, hill climbing, or starting may cause symptomatic iliopsoas syndrome. (38)

Iliopectineal bursitis (with or without associated snap) is less common than greater trochanteric pain syndrome and often an unrecognized cause of anterior hip pain. (40)

Runners with iliopsoas syndrome may report anterior hip pain that is exacerbated by activity or resisted hip flexion. (41) The pain may radiate down the medial thigh toward the knee and is often relieved with rest. (41) Limping, hip internal and external rotation weakness, restricted hip extension or a shortened stride may all be noted on physical examination. (38)

Ischial bursitis is rather uncommon, however could occur if a runner falls onto his or her ischial tuberosity. Proximal hamstring tendonitis, ischial apophysitis, and avulsion injuries may all mimic ischial bursitis and must be considered when evaluating a runner with pain in this area. (27)

Individuals with ischial bursitis may report localized pain or warmth that worsens with hill running, sprinting or prolonged sitting. Physical examination will reveal localized tenderness over the ischial prominence that is exacerbated by resisted hamstring strength testing. (27)

Hip bursitis is primarily a clinical diagnosis and diagnostic imaging is often unnecessary. Plain radiography may demonstrate variably sized linear or round calcifications that are isolated or clustered adjacent to the greater trochanter with greater trochanter pain syndrome while radiography is typically normal with iliopsoas and ischial bursitis. (36)

MRI may demonstrate a homogenous focus of bright signal intensity on T2 weighted or short echo time inversion-recovery images. (36)

### **Retrocalcaneal Bursitis:**

Inflammation of the retrocalcaneal bursa is caused by repetitive motion of the Achilles tendon over the posterosuperior aspect of the calcaneus or by pressure from the heel counter in the shoe, or a combination of both. Dorsiflexion of the ankle will increase the pain. (42)

Radiographs may help to identify an anatomical cause, which is typically a hatchet-shaped calcaneus. A Fowler and Philip angle of greater than 75 degrees or more is abnormal. (42)

### **Bone:**

In contrast to tendon, the purpose of the skeletal system is to provide rigid kinematic links and muscle attachment sites and to facilitate muscle action and body movement. (43) Bone is a highly vascular tissue allowing for a high capacity for self-repair. Bone also adapts to the mechanical demands placed on it. (43)

The structure of bone is primarily made up inorganic minerals, mostly calcium and phosphate, which account for approximately 60-70% of the dry weight and give bone its solid consistency. (43) The remaining 25-30% of the dry weight of bone is made up of Type I collagen fibers which is tough and pliable while resisting stretch. (43) Water is also fairly abundant in live bone and accounts for 25% of the total weight. (43)

All bones are comprised of two types of osseous tissue: cortical (also known as compact) and cancellous (also known as trabecular) bone. (43) Cortical bone is dense while cancellous bone is organized in a loose mesh structure to allow for red marrow to pass between. Cortical bone always surrounds cancellous bone; however the relative quantity of each type varies within individual bones according to the functional requirements. (43) In the hip, thigh, and knee region, the femur is comprised of a greater amount of cancellous bone at the head and neck and made up of more cortical bone in the shaft and distal segment. (43) In the ankle region, the tibia and fibula have a greater amount of cancellous bone at their distal ends then in the mid-shaft region. The talus bone is also comprised of more cancellous bone and this is due to the functional weight bearing demands of the bones in this region. (44)

Bone is considered a two-phase composite material (collagen and ground substance) and in essence is a strong, brittle material embedded within a weaker more flexible one

allowing for a combined substance that is much stronger for their weight than either substance alone. (43)

Like tendon, stress and strain values can be obtained for bone as well. Cortical bone is stiffer than cancellous bone, withstanding greater stress but less strain before failure. In vitro, cancellous bone may sustain up to 50% of strains before yielding, while cortical bone yields and fractures when the strain exceeds 1.5-2%. (43) In general, bone strength and stiffness are greatest in the direction in which daily loads are most commonly imposed. (43)

Bone behaves differently under various loading. Tensile stress is the primary cause of fracture in bones made up mostly of cancellous bone (ex: femoral neck fracture and calcaneus fracture adjacent to the attachment of the Achilles tendon). (43) Compressive forces, or many small forces directed toward into the surface of the bone, will cause a shortening and a widening to occur within the bone. (43) Shear forces, or many small forces acting on the surface of the bone on a plane parallel to the applied load, will cause deformation in an angular manner. Fractures caused from Shear forces primarily are seen in cancellous bone. (43) Cortical bone on the other hand can withstand greater stress in compression than in tension and greater stress in tension than in shear. (43)

Bending occurs in a bone when a combination of tension and compression occur. A common example of this is known commonly as a “boot top” fracture. The most common example of this three point bending injury occurs when one bending moment is applied to the proximal tibia of a skier falling forward over the top of a ski boot. An equal moment is produced by the foot and ski acting on the distal tibia. A tensile stress is imparted on the posterior side and compressive stress is applied on the anterior side. The tibia and fibula are then fractured at the top of the boot. (43) While not very common at all this could also be seen in a runner who while running in a grassy field doesn't see a hole and ends up falling into the hole with one foot. Depending on the age of the runner, the depth of the hole and the running speed the force in which the runner falls could be enough to cause a bending injury at the same region.

In Torsion a load is applied to a bone in a manner that causes it to twist about an axis and a torque is produced within the bone. (43) Fracture patterns for bone loaded in torsion suggest that the bone fails first in shear with the formation of an initial crack parallel to the neutral axis of the bone. A second crack will also generally form and this one forms along the plane of maximal tensile stress. (43) The polar moment of inertia takes into consideration both the cross sectional area and the distribution of bone tissue around a neutral axis. The larger the polar moment of inertia, the stronger and stiffer the bone. (43) In the distal tibia while there is a larger cross sectional area, the distal section is also subjected to much higher shear stress because much of the bone tissue is distributed close to the neutral axis. The result is that most torsional fractures in the tibia occur distally rather than proximally. (43) In the femur the opposite is true. Most fractures occur at midshaft or more proximal in the head or neck region because again the majority of the bone tissue is distributed close to the neutral axis. (43)

Finally Combined loading constitutes what bone goes through on a daily basis. That is multiple stresses will be applied over living bone because of the stresses from internal and external factors and their irregular geometric shape. (43) During jogging a stress value calculated at the tibia will show compressive stress predominating at toe strike followed by high tensile stress during push off. Shear stress is present, however typically low throughout the stride due to slight external and internal rotation of the tibia in an alternating pattern. As speed is also increased both the stress and strain will increase as well. (43)

Muscle activation can also an effect on forces exerted through bone tissue. In the hip joint during running, bending moments are applied to the femoral neck and tensile stress is produced on the superior cortex. Contraction of the gluteus medius muscle produces compressive stress that neutralizes the tensile stress, with the net result that neither compressive nor tensile stress acts on the superior cortex. Thus the muscle contraction allows the femoral neck to sustain higher loads than would otherwise be possible. (43)

Resistance to fatigue behavior is greater in compression than in tension and approximately one million cycles of loading corresponds to the number of steps in 1000 miles. A total distance of less than 1000 miles could cause a fracture of the cortical bone tissue and is consistent with stress fractures reported by military recruits training upward of 1000 miles of running in a relatively short period of time (6 weeks). (43)

Clinically bone fracture is classified under three general categories: low-energy, high-energy, and very high energy. (43) Most running injuries are classified in the low energy range and will typically be produced from fatigue in which a low load is applied over many repetitions. The load rate is clinically significant because it influences both the fracture pattern and the amount of soft tissue damage (if any) at fracture. (43)

Bone healing occurs through migration of blood vessels and connective tissue from the outer surface allowing for callous formation (a cuff of dense fibrous tissue; woven bone) which helps to stabilize the area. (43) The callous area significantly increases the area and polar moment of inertia, thereby increasing the strength and stiffness of the bone in bending and torsion during the healing period. (43) After healing is complete the callous is reabsorbed and the bone returns to as near its normal size and shape possible.

### **Osteoarthritis:**

Osteoarthritis (OA) affects numerous individuals, produces significant disability and generates substantial economic costs. (45, 46, 47) However, there is still significant controversy in the literature concerning the relationship between running and the development of osteoarthritis. (48, 49, 50)

### **Hip:**

Obesity, genetic susceptibility, postmenopausal hormone deficiencies, occupational activities, educational level and advanced age are all known to increase the risk of hip OA. (46, 51) In addition, prior injuries, hip trauma, acetabular dysplasia, slipped capital

femoral epiphysis, osteochondritis desiccans and Legg Calve-Perthes disease are also predisposing factors to hip OA. (45, 51)

It is believed by some that the repetitive mechanical loads from running may be a risk factor for subsequently developing hip OA. (48) Some have even suggested that a dose response relationship exists between exercise duration and hip OA, since the relative risks of developing OA increase with higher exercise exposures (>800 aggregate hours of sporting activities by age 50 years). (46, 48)

In stark contrast however, and this is where the controversy lies, other researchers have found no significantly increased risk of hip OA due to running. A longitudinal case-controlled study of older male and female runners (mean age 66 years) observed no accelerated development of radiographic hip OA versus non-runner controls. (52)

Another large, longitudinal study of physically active men and women concluded that participation in moderate intensity running did not increase the risk of self reported or physician diagnosed hip OA. (49)

Runners with hip OA are often older (>60 years) and report insidious, persistent (>3 months) groin pain or tenderness that is aggravated by sitting. (53, 54) The pain is frequently deep, aching, and poorly localized with radiation into the anterior thigh. Affected runners may also note decreased hip adduction, internal rotation or external rotation that gradually intensifies. Symptoms will typically worsen at the end of the day or after running. Brief morning stiffness (<60 minutes) may be reported, but the duration is shorter than that for rheumatoid arthritis. (54)

Physical exam findings include painful and decreased hip ROM, particularly internal rotation ( $\leq 15$  degrees). (54) Regional muscle weakness is common with more advanced disease and crepitus may be present, but warmth and swelling are typically uncommon. (53) OA is typically associated with a heterogeneous radiographic disease development, but approximately 20% of people with hip OA progress radiographically after a year. (55)

Typical radiographic findings of OA include irregular joint space narrowing, osteophytes formation, cyst formation, Subchondral sclerosis and femoral head deformation. (54)

Bony erosions or demineralization are uncommon. Although osteophytes seen on radiographs best separate those with hip OA from controls, joint space narrowing measured at the narrowest interbone distance in millimeters may correlate better with hip pain. (54, 55) In some cases, CT or MRI may be helpful to characterize the articular cartilage defects and identify concomitant pathology such as labral or ligamentous abnormalities. (27)

### **Patellofemoral Pain Syndrome:**

Patellofemoral pain syndrome (PFPS) is the most common diagnosis for knee pain in athletic and nonathletic populations; the incidence may be twice as high in female athletes compared with their male counterparts. (56, 57)

The PFPS pain syndrome is an amalgam of diagnoses and generally can be classified into patellar instability, PFPS with malalignment, and PFPS without malalignment. (58) Within these categories there are thirty eight subcategories for each specific pathological condition. (59)

It should be very simple to classify individuals into one of these three categories by answering the following three questions: 1) Is the problem truly related to the patellofemoral joint or its related structures? 2) Is malalignment present? And 3) Is instability present? (59)

The current theory of pathogenesis in PFPS is injury to the subchondral bone from patellar maltracking and increased patellofemoral joint reaction forces. It has been proposed that the actual pain generator is the loading of nerve endings (ie, a degenerative neuroma) in the patellar retinaculum which causes a resultant synovitis. Other pain

generators may exist in PFPS, such as irritated infrapatellar fat pad, plica, bursa, tendons, and apophyses. (60)

Biomechanical structural problems may contribute to patellofemoral pain as well. Muscle imbalances may exacerbate knee pain. Weak quadriceps musculature, particularly the vastus medialis obliquus (VMO) portion, has been implicated in patellofemoral pain. When the VMO is weak or inhibited, lateral vector forces that are created by the vastus lateralis, iliotibial band (ITB), and lateral retinaculum become dominant. Thus the patella becomes displaced laterally. Tight lateral structures (ITB and lateral retinaculum) exacerbate this phenomena. Specifically in runners, a tight ITB and tensor fascia lata muscle, coupled with weak gluteus medius, creates excessive internal rotation of the femur and a lateral pelvic tilt. Tight hamstrings and gastrocnemius musculature also may exacerbate PFPS by increasing knee flexion and creating greater patellofemoral joint reaction forces. In addition, hyperpronation seems to predispose runners to PFPS. (58)

The classic presentation of PFPS is an insidious onset of progressively severe diffuse anterior knee pain, especially with loading activities that involve repetitive flexion and extension, such as running. It may manifest as an ill-defined, usually bilateral, ache which is aggravated by hill training or stair climbing. Knee buckling can occur occasionally as a result of a painful reflex inhibition of the knee extensor mechanism. Other complaints may include crepitus or a “catching” sensation that is experienced with knee joint flexion and extension; however crepitus may be common, even in asymptomatic individuals. Prolonged sitting with knee flexion, such as on an airplane flight or in a theater, may aggravate patellofemoral pain and lead individuals to extend their knee and legs into the aisle, also known as the “movie theater sign.” (58)

Differential diagnosis of knee pain in the runner can be best broken down into the following regions of the knee:

Medial: PFPS, plica, medial meniscus tear, medial collateral ligament sprain, intra-articular, osteoarthritis

Lateral: PFPS, iliotibial band syndrome, popliteus muscle, lateral collateral ligament sprain, lateral meniscus tear, intra-articular, osteoarthritis

Anterior: PFPS, quadriceps tendonitis, patellar tendinopathy, patellar instability, Hoffa's Syndrome, patellar osteochondral defect, osteoarthritis, bursitis

Posterior: Baker's cyst, hamstring tendinopathy, popliteus (58)

### **Patellofemoral Instability:**

Patellofemoral instability is usually diagnosed in persons who have a history of subluxation or dislocation. Occasionally, it is somewhat confusing when "giving way" is reported, as this can simply be a reflex inhibition of the quadriceps secondary to pain. The direction of instability is usually laterally with medial instability almost always secondary to iatrogenic causes. The number of episodes is important, as first time "dislocators" and infrequent "subluxators" should have a trial of non-operative therapy or limited arthroscopic evaluation for documented osteochondral lesions; (59) whereas, recurrent instability is an indication for surgical treatment.

### **Patellofemoral Pain with Malalignment:**

Patellofemoral Pain with Malalignment implies that the static and/or dynamic restraints of the patellofemoral joint are insufficient to allow normal patellar tracking. This can include abnormal bony alignment of the limb, abnormal static soft tissue restraints, and abnormal dynamic soft tissue restraints. The concepts of subluxation and tilt have been developed to describe patellofemoral malalignment problems. Radiographs and clinical exam will help the clinician to discern whether subluxation and/or tilt are present. (59)

Malalignment may be a result of increased Q-angle. The Q-angle represents the frontal plane angle of the quadriceps resultant force on the patella and the tibial tuberosity. It is

defined by the intersection of the line from the anterior superior iliac spine (ASIS) to the center of the patella and a line connecting the center of the patella to the tibial tuberosity. The Q-angle can be measured reliably and it provides a reasonable estimate of the quadriceps muscles' angle of pull on the patella in the frontal plane. (61)

One downside is that the Q-angle is typically measured statically and studies have demonstrated static measures to be poor predictors of dynamic dysfunction. Therefore a dynamically measured Q-angle may provide more information than a static measure (62, 63)

Anatomic causes of increased Q-angle include excessive femoral anteversion, external tibial torsion, genu valgum, and foot hyperpronation. At the present time, there is very little conclusive evidence, even when Q-angle is measured dynamically, that links a relationship between rearfoot motion and Q-angle.

Observation of the individual in a weight bearing position and careful physical examination of the hip, knee, and ankle are crucial to the evaluation of limb alignment. The Q-angle is an attempt to measure the vector forces applied to the patella which are responsible for properly guiding its tracking throughout the range of motion. (59)

There is much debate in the literature as to what the upper limits of the Q-angle should be (64, 65, 66), however approximate upper limits for adults would be 11 degrees for males and 18 degrees for females. (59)

In regards to patellar tilt, a tight lateral retinaculum may be responsible for causing patellar tilt and excessive pressure on the lateral patellar facet producing the excessive lateral pressure syndrome. This diagnosis is supported by limited medial patellar glide with clinical and radiographic evidence of lateral patellar tilt. (67)

The medial stabilizers are also crucial to proper patellofemoral stability and tracking. The vastus medialis obliquus provides dynamic stability, with static stability provided primarily by the medial patellofemoral and patellomeniscal ligaments. (59)

### **Patellofemoral Pain without Malalignment:**

There are numerous painful conditions of the patellofemoral joint that exist in the absence of any perceivable malalignment. Increased contact pressures and pain may result from coexisting tight medial and lateral retinaculæ. Limited patellar mobility with normal tracking and alignment define this diagnosis. (59)

Pathologic synovial plica can also cause patellofemoral pain. A palpable band or snapping, especially over the medial femoral condyle, should be sought. This is often a diagnosis of exclusion and can only be confirmed at arthroscopy. Of note is that plica are present in many knees, however are only symptomatic in a small percentage individuals. (68)

Fat pad syndrome (Hoffa's Syndrome) which involves either inflammation or fibrosis of the infrapatellar fat pad can occur as an overuse or posttraumatic phenomenon. Hoffa's test in which the examiner palpates the fat pad on either side of the patellar tendon as the involved knee is brought from flexion into full extension will be painful if the fat pad is inflamed. Osteoarthritis, among other causes, should be ruled out before concluding that the fat pad is the primary source of pain. (59) MRI will be helpful in determining this diagnosis. (69)

Patellofemoral osteoarthritis is diagnosed by correlating patellofemoral pain with radiographic changes consistent with joint degeneration. Differentiation of idiopathic and posttraumatic subtypes is based on history. (59)

Patellar tendonitis and quadriceps tendonitis are overuse conditions that are seen frequently in runners and individuals involved in jumping activities. Diagnosis of these

conditions is based on careful palpation of the tendons in both flexion and extension. Pain on palpation near the patellar insertion is present in both patellar and quadriceps tendonitis. These are usually self-limiting conditions which respond well to non-operative modalities. (59)

Apophysitis of the tibial tubercle (Osgood-Schlatter disease) and distal patella (Sinding-Larsen-Johanssen syndrome) occurs in the skeletally immature, especially those involved in sports requiring repetitive loaded knee flexion. Osgood Schlatter disease usually occurs during the adolescent growth spurt, with Sinding-Larson-Johanssen syndrome usually occurring prior to the growth spurt. Fragmentation of the tibial tubercle or irregular calcification of the inferior patellar pole may be seen on radiographs. The involved area is tender and usually prominent on physical examination. (59)

Medial retinaculitis is a rare condition that is almost exclusively seen in runners and probably represents a fatigue tear in the medial capsular insertion into the patella. A positive bone scan in the medial edge of the patella confirms the diagnosis. (59)

The history and physical evaluation of the runner who has knee pain should include analysis of the kinetic chain. Plain radiographs, particularly lateral and “sunrise” (or “skyline”) views may be helpful in evaluating the patellofemoral joint. (70)

Sunrise radiographs are axial views that are taken with the knee flexed 30 degrees or 45 degrees. If the patellofemoral joints shows joint space narrowing, osteophytes, subchondral sclerosis and cysts, patellofemoral osteoarthritis should be suspected. Osteochondral lesions sometimes can be seen with these views. The lateral radiograph may demonstrate patella alta, rotational malalignment, or trochlear dysplasia. More commonly, particularly in the younger female runner who has PFPS, these radiographs are normal. Occasionally, MRI is useful in identifying the quality of the patellar cartilage pathology and ruling out other knee pathologies. (58)

### **Stress Fractures:**

Stress Fractures constitute 10-20% of all injuries seen in sports medicine clinics, and 7-10% of these affect the femurs, pubic rami, iliac crests and sacroiliac joints. (71, 72)

Women are 3-10 times more likely in general to sustain a stress fracture than men. (71, 73) The most common locations for stress fractures that cause hip and groin pain are the femoral neck and pubic rami. (74) Femoral stress fractures may occur on the tension (superior) or compression (inferior) surface with dramatically different implications. (75)

Tension surface femoral neck stress fractures often affect older runners and are at a significant risk of nonunion, deformity, malunion or avascular necrosis. In contrast, compression surface femoral neck fractures occur in younger runners and generally do well with protected activity followed by a gradual return to running. (71)

Stress fractures originate either from abnormal forces on normal bones (fatigue fractures) or normal forces on abnormal bones (insufficiency fractures). Most affected runners develop fatigue fractures, of which two thirds are due to training errors, competitive racing and excessive mileage. (76, 77)

Risk factors can include amenorrhea, disordered eating, osteoporosis, narrow tibial bone widths, running shoes with excessive mileage on them, coxa vera, rapid increases in training, chronic glucocorticoid use, smoking, hyperparathyroidism, hyperthyroidism, malabsorption syndromes and calcium deficiencies. (76, 77) A delay of at least six weeks between symptoms onset and clinical diagnosis is not uncommon for stress fractures as symptoms and signs may be subtle at first. (78, 79)

It is important to obtain a thorough history including training patterns (intensity, mileage, running surfaces), shoe wear, prior stress fractures, and technique modifications. With female runners, menstrual cycle regularity and eating habits should also be asked about and addressed. (80)

Physical examination may occasionally reveal localized tenderness in palpable bones. Since the hip joint itself is very deep, it is often difficult or impossible to palpate it directly. Hip ROM is typically abnormal and painful at the extremes, particularly with internal rotation, adduction and flexion. (81)

Pain may be exacerbated by weightbearing (standing sign) or hopping (hop test) on the affected leg (73, 76) A fulcrum test (putting one arm under the affected leg and pushing downward on the distal thigh) may be positive with a femoral stress fracture as well. (76)

Plain radiographs are often the initial imaging study performed however they have a low sensitivity and visible changes may take several weeks to occur. (73) The classic findings on radiograph consist of focal periosteal reaction, cortical disruption and trabecular sclerosis. (82) Bone Scans on the other hand may be positive within hours of a stress fracture. Triple phase bone scans consist of a flow phase (immediately following injection), a pool phase (5-15 minutes after injection) and a delayed phase (2-3 hours after injection). (80)

Stress fractures classically manifest a focally increased uptake on the delayed phase. Bone scans generally have high sensitivities, but false negative results have been reported in runners. (83) Also bone scans have relatively lower specificities and positive predictive values. (80)

MRI is considered the most useful study to evaluate suspected stress fractures. MRI can define the extent and location of stress fractures with better specificity, structural visualization and spatial resolution than other diagnostic imaging studies. Unfortunately the cost, long study duration, and availability are disadvantages for using MRI in diagnosis of stress fractures. (80)

### **Medial Tibial Stress Syndrome:**

Medial Tibial Stress Syndrome (MTSS) is an exercise induced localized pain along the distal two thirds of the posteromedial tibia and can be a debilitating injury in runners. (123) Incidence in MTSS is typically higher in females than males (124), and improper foot biomechanics including static pronated foot, lower standing foot angle (angle between the medial malleolus-navicular tubercle-first metatarsal head), varus rearfoot and/or forefoot, and greater maximum pronation and pronation velocity have all been associated with this condition. (125, 126)

Unfortunately, most studies that indicated that navicular drop was indicative of persons that would develop MTSS were performed post injury and also to date there is no standard criterion for what defines an abnormal navicular drop. (123) Plisky et al. determined that based on measurements taken prior to injury and post injury, navicular drop may not be an appropriate marker for those runners that will develop MTSS. (123)

#### **Calcaneal and Talar Stress Fractures:**

Calcaneal and Talar stress fractures are not very common, however patients may present with heel pain with running or walking that is relieved with non-weightbearing. Diagnostic imaging with bone scan, CT scan or MRI will confirm this diagnosis. (16)

#### **Navicular Stress Fracture:**

This is a common stress fracture in runners, so it should be ruled out in any runner who presents with vague midfoot pain. Differential diagnosis includes extensor tendinopathy, which usually is more tender to palpation on the plantar surface and with resisted foot dorsiflexion, and midtarsal joint sprains, which are usually associated with a discrete event, such as twisting the foot or tripping. Physical examination is remarkable for tenderness directly over the bone when proximal dorsal surface is palpated (often called the “N” spot). Pain is also made worse by hopping. Diagnostic imaging by bone scan, MRI, or CT scan will confirm the diagnosis. (16)

### **Metatarsal Stress Fractures:**

Stress fractures in this region are very common with the second and third metatarsals fractured the most often. The second metatarsal is particularly vulnerable because the proximal head is tucked between the medial and lateral cuneiforms and is immobile. (84)

Fifth metatarsal stress fractures are uncommon in runners and may be more difficult to treat. Biomechanical risk factors for foot fractures include: high longitudinal arch and cavus type foot, pes planus foot and excessive pronation, high mileage, sudden increase in mileage, training on hard surfaces, and nonmenstruation in women. (85)

Individuals usually present with foot pain that is worse with running and better with rest. At first, symptoms may be intermittent, but begin to occur with all activity. Individuals often present 4 to 5 weeks after a sudden training increase. The most common physical examination finding is point tenderness over the fracture. (16)

Imaging confirms the diagnosis. Plain films can remain normal for 3 to 6 weeks after symptoms develop. The first change seen is subperiosteal bone formation, however sometimes changes are never seen. Bone Scans will be positive in 20% to 40% of cases in which clinical suspicion is high but plain films are normal. (85)

MRI is also sensitive in showing stress fractures. Some investigators believe that MRI is too sensitive however and may sometimes show bony reaction in asymptomatic individuals. For that reason, grading scales have been developed for MRI changes that correlate with prognosis. (85)

### **Metatarsalgia:**

This is a common condition in runners which should be considered once metatarsal stress fracture has been ruled out. Diagnosis is made clinically and individuals will complain of pain on the plantar surface of the metatarsal heads that is worse with running and better at rest. Tenderness in this area is found on physical examination. This is because the first

and second metatarsal heads may accept increased force at impact because of an overpronated foot. (84)

### **First Metatarsal Phalangeal Conditions:**

Running can aggravate common conditions of the first metatarsal phalangeal, such as hallux rigidis and hallux valgus. Hallucis sesamoids can also be aggravated by running, especially sprinting. Individuals will often have pain at the dorsal surface of the interphalangeal joint of the great toe with weightbearing and walking. Physical examination will also reveal tenderness and swelling in this area. It may be difficult to differentiate between stress fractures and sesamoiditis which is pain and swelling of the tendon around the sesamoids. (86)

### **Articular Cartilage:**

Articular cartilage is made up primarily of water (60-80%) with the other 20-40% being made up of type II collagen, ground substance, and chondrocytes. Articular cartilage is both aneural and avascular, however the Subchondral bone will feel pain and report this back along the afferent pathways to the brain. The function of articular cartilage is to increase contact area at the joint, decrease contact pressure, and decrease stress transmitted to Subchondral bone. (87)

Injury to articular cartilage generally occurs at higher speeds of loading, in which there is less time for water to be displaced which in turn causes the collagen structure to load excessively. If loaded often enough and with enough speed, failure and damage to the cartilage will occur. Over time an increase in stiffness could also result in osteoarthritis formation. Blunt trauma, penetrating injuries, frictional abrasion, or sharp concentration of weightbearing forces can all cause injury. (87)

Most cartilage injuries in adolescent runners are overuse injuries rather than sudden traumatic events and occur at traction apophyses rather than the growing physes. As growth plate cartilage has poor resistance to shear forces, so too is adolescent articular

cartilage at risk from shear strain and repetitive loading. For example, osteochondral defects at the anterolateral portion of the talus can occur and may be reduced with appropriate footwear and by modifying the frequency and duration of training. (87)

### **Hip Apophysitis/Avulsion Fractures:**

Apophysitis symptoms generally present as gradually increasing, localized, dull pain that is exacerbated with running. In contrast, avulsion fractures are typically produced by a forceful, eccentric muscle contraction during sprinting that produces immediate pain, swelling, limping, and disability. Affected runners may also feel or hear a pop. (27)

Physical findings would reveal localized pain, ecchymosis, swelling and tenderness near the tendon-bone interface. Also resistance testing would exacerbate the pain with range of motion being limited. On occasion a palpable lump or nodule may be present. (27)

The areas most frequently affected in the hip are the iliac crest, anterosuperior iliac spine (ASIS), AIIS, ischial tuberosity, greater trochanter and lesser trochanter. (27) The iliac crest serves as the attachment for the abdominal oblique, transverse abdominus and gluteus medius muscles. Excessive force from accentuated arm motion across the trunk in running can cause significant irritation at the iliac crest bone-tendon interface, however avulsion fracture at this site is rare. (27) The ASIS provides attachment for the sartorius muscle and is frequently injured during sprinting or hurdling. (27) The AIIS serves as the origin of the rectus femoris muscle and this may also be affected during sprinting. (27)

The ischial tuberosity serves as the origin for the medial and lateral hamstrings and is the most common site of pelvic avulsion fractures in young runners. (27) Apophysitis and avulsion fractures of the ischial tuberosity often result from an eccentric contraction of the hamstrings with a flexed hip and extended knee. Often these injuries may be misdiagnosed as hamstring tendonitis or bursitis. (27)

Diagnostic imaging with plain radiographs is better than MRI at identifying avulsion fractures and CT scan can assist with diagnosis of apophyseal injury. (27)

### **Acetabular Labral Tears:**

The labrum is a fibrocartilaginous rim that deepens the acetabulum and stabilizes the femoral head. The posteromedial and anterosuperior aspects of the acetabular labrum are particularly vulnerable to injury due to mechanical stresses or excessive twisting in sport. (88, 89)

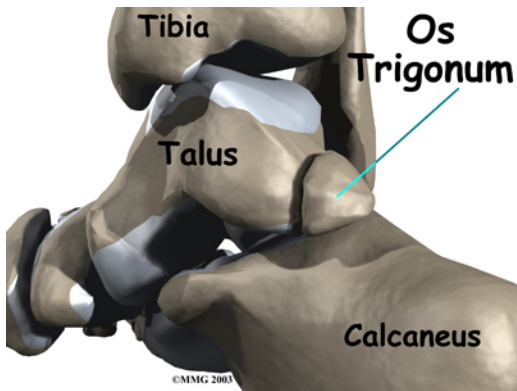
Acetabular dysplasia is associated with a labral tear up to 30% of the time, and labral tears may also be related to recurrent hip subluxations. (90, 91) Typically runners with an acetabular labral tear will present with painful episodes of anteromedial snapping or clicking, intermittent hip instability and locking or decreased hip internal rotation that must be distinguished from osteoarthritis, snapping hip syndrome and iliotibial band syndrome. (89, 91)

Plain radiographs have a low sensitivity for labral tears but may help differentiate hip dysplasia from other conditions. (91) MRI with gadolinium enhancement has significantly improved the accuracy of MRI with a reported sensitivity of 90% for acetabular tears and positive studies should always be followed up with arthroscopy, which is currently the most effective way to diagnose and treat labral injuries. (92)

Most labral tears do not heal conservatively and incomplete healing increases the risk of chondral defects and secondary osteoarthritis. (89)

### **Os Trigonum Syndrome:**

Os Trigonum syndrome is often seen in adolescent runners. The Os Trigonum is an accessory bone seen in only about 15 percent of people. This bone develops as a secondary ossification center at the posterior aspect of the talus. (Figure 2)

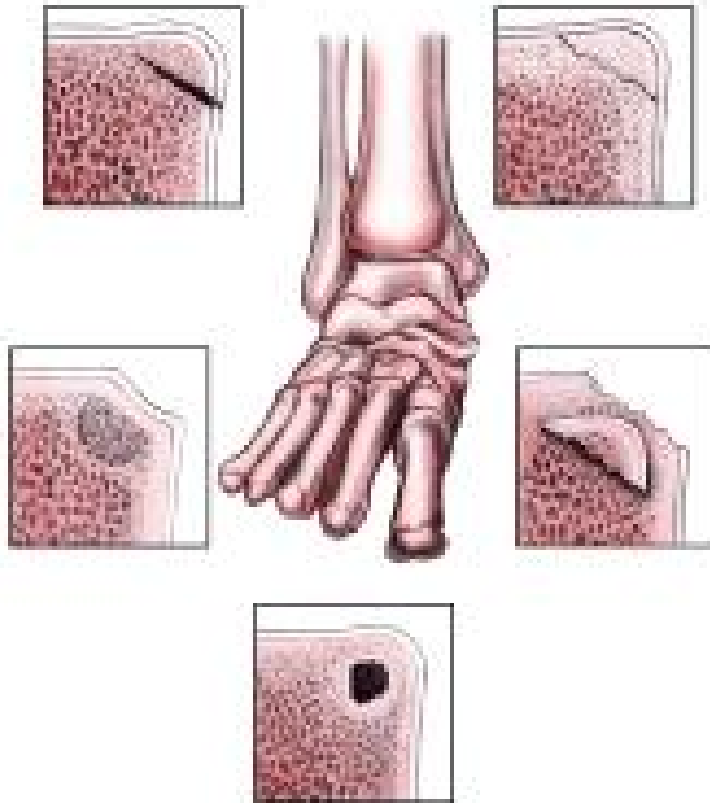


(Figure 2): [www.eorthopod.com](http://www.eorthopod.com) (accessed 12/7/06)

In general, symptoms of this region occur due to impingement of the soft tissue between the process and the posterior aspect of the tibia when the ankle is held in plantarflexion. (93) Dorsiflexion can also stretch the posterior ligament where it attaches to the Os Trigonum and irritation can occur due to the Flexor Hallucis Longus tendon which also passes nearby. This can be seen in competitive runner's especially in cross country or those performing hill workouts. Diagnosis is made with careful history and examination along with plain radiograph. (93)

### **Osteochondral Lesions of the Talus:**

Osteochondral lesions of the talus are common in adolescents and older runners and most especially after an inversion injury or sprain, but can also occur from microcirculatory impairment. It is estimated that injuries to the talar dome occur in 7% to 22% of all ankle sprains. (16) Patients with this type of injury will present with diffuse ankle pain with swelling and occasional locking or catching in the joint secondary to loose fragments. In runners with persistent pain after an ankle sprain, this type of injury should be ruled out to ensure complete recovery. (93) (Figure 3) Diagnosis is generally made with plain radiographs including a mortise view of the ankle.



**(Figure 3): Osteochondral lesions of the talus**

<http://www.emedicine.com/Orthoped/topic638.htm> (accessed 12/07/06)

**Calcaneal Apophysitis:**

The vertically oriented epiphysis of the secondary ossification center of the calcaneus is susceptible to shearing forces from the strong gastroc-soleus complex. This condition will present in the adolescent runner (8 to 12 years old) and more commonly in boys. Most cartilage injuries in adolescent runners are overuse injuries rather than sudden traumatic events and occur at traction apophyses rather than the growing physes. (93)

Risk factors include excessive forefoot varus, pes cavus or pes planus, and also reduced flexibility because of growth spurt limitations. (94)

Any single factor or combination of factors may predispose to poor shock absorption in the adolescent foot, resulting in excess forces about the heel. Symptoms occur during or right after running where the Achilles apophysis is tender on palpation. (94)

Plain radiographs may show sclerosis and fragmentation of the apophysis; however, they may be best used to rule out calcaneal stress fractures and other lesions. (93)

### **Ligament:**

Ligaments serve three major functions in the body. First, they provide proprioceptive information for joint function. Second, they contribute to the stability of the joint function thereby preventing excessive motion (although debatable how much stability they actually provide within functional range; may act more as checkreins). Third, ligaments act as guides to direct motion. (21)

Ligament injuries are sometimes very difficult to document in part because the ligaments often are deep structures adjacent to or beneath many other tissues. Ligamentous injuries in runners are not as common in the hip or knee as they are in the ankle and therefore this paper will concentrate on the ankle region

### **Ankle Region:**

In the ankle, the ligament structures are often easier to palpate and are therefore generally easier to diagnose. Three primary groups of ligaments are present about the ankle complex: the lateral ligament complex, the deltoid ligament on the medial side, and the ligaments responsible for making the syndesmosis at the distal tibia and fibula. (95)

The lateral ligament complex is comprised of the Anterior talofibular ligament (ATFL), the Calcaneofibular Ligament (CFL), and the Posterior talofibular ligament (PTFL).

The ATFL is an intracapsular structure and requires the lowest maximal load to failure of the lateral ligaments. This accounts for its highest incidence of failure in this complex even though it paradoxically has the highest strain to failure of that group. (95) The ATFL is also the most important ligament in preventing talofibular instability and is the primary stabilizer to ankle inversion while in plantarflexion. Because of this, the ATFL is also the first ligament torn in an inversion injury. (95)

The CFL is an extra-articular structure and is covered by the peroneal tendons. The CFL indirectly aids talofibular stability due to its anatomic location. Finally the PTFL is the strongest ligament in the lateral complex. This ligament is rarely injured due to the fact that it is only taut in severe dorsiflexion and if injured does not lead to any ankle instability. (95)

One other ligament not typically included within the lateral complex is the Lateral talocalcaneal ligament (LTCL). This ligament blends with the ATFL and the CFL and extends from the talus to the calcaneus. The primary function of the LTCL is to assist with Subtalar stability. (95)

The Medial or Deltoid ligament attaches from the medial malleolus of the tibia to the tarsal bones. There are four parts to this ligament: the tibionavicular, the anterior and posterior tibiotalar, and the tibiocalcaneal. The function of this ligament is to strengthen the joint, hold the calcaneus and navicular bones against the talus, and to help maintain the medial side of the foot and the medial longitudinal arch. (5) Sprain of this ligament will usually cause significant swelling, tenderness, and ecchymosis to occur over the medial ankle. (96) If more than 4 mm of widening at the ankle mortise is imaged radiologically, syndesmosis injury has more than likely occurred as well. Complete tear of the deltoid ligament is rare and in general is associated with ankle fracture. (96)

Lateral ligament complex sprains are the most frequent injury sustained by athletes. Ankle sprains produce 25% of all lost time due to injury in football, basketball and cross-country running. (95)

Ligament sprains, or damage to the ligament as a result of an increase in force due to loading and unloading of the joint, can be classified in three grades: grade I (mild, no increase in laxity); grade II (moderate, slight but not significant laxity); grade III (severe, complete disruption with significant laxity). (97)

With a grade I ligament sprain there is no laxity of the tissues and no residual instability as full function and strength are maintained. These injuries generally resolve in less than two weeks. In a grade II sprain, there is mild laxity, slight decrease in function, mild decrease in strength, and potential for loss of proprioception. These injuries generally require 2 to 6 weeks for full return to functional activity. And in grade III sprains there is generally gross instability and potential for complete loss of full function, strength, and proprioception. In general these injuries last longer than 6 weeks and some studies show that only 25-60% of individuals are symptom free 1-4 years after injury. (95) In 65% of grade III sprains the AFTL is the only ligament torn and 20% result in bi-ligament tears (AFTL and CFL).

In general ligament healing occurs in three phases: phase I (acute inflammation and reaction); phase II (repair and regeneration); phase III (remodeling or maturation). Phase I of healing occurs during the first 72 hours after injury and is characterized by hematoma formation and swelling, redness, warmth, and pain. A potent vasodilator-histamine is released from platelets and most other cells due to injury. Prostaglandin release, among with other inflammatory cells (serotonin and bradykinins) follows and allows for increased permeability of the capillaries and ultimately the start of the healing process. (97) At this point collagen synthesis also occurs and scar formation increases the total mass of the ligament. (97)

Phase II lasts from 48 to 72 hours after the injury until approximately 6 weeks after the injury. This phase is characterized by the resolution of inflammation (although water content is still increased) and the beginning of healing. (97) It is at this point that cellular tissue undergoes changes in the collagen cross linking profiles. (97)

Phase III requires 12 months or more to become maximal. Healing ligament becomes increasingly contracted and demonstrates increasing tensile strength. Even at 12 months in most cases the original tensile strength is not regained (50% to 70% is the probable range and underscores one reason why recurrent ligament sprains are so prevalent). (97)

In general, there need to be three specific criteria met in order for optimal ligament healing to occur. The first condition that needs to be met is that the torn ligament must remain in continuity or be confined within a well-vascularized soft tissue bed. The second condition that must be met is controlled, functional stresses must help stimulate and direct the healing response. And finally the third condition that must be met is that at the same time there must be protection against harmful stresses during the collagen synthesis and remodeling and maturation phases. (97)

Tears in the lateral ligaments will in general follow a predictable pattern. The AFTL is usually the first to tear in an inversion injury, next is the anterolateral capsule, and then the distal tibiofibular ligament. If force is excessive the CFL will tear followed finally (if enough force) by the PTFL which may also be associated with ankle dislocation, distal lateral malleolar avulsion or spiral fracture, medial malleolar fracture, or talar neck or medial compression fracture. (95) Interestingly enough roughly 86% of ankle ligament tears are midsubstance with the remaining 14% being avulsion fracture injuries. (97)

When differentially diagnosing ankle injuries, it is important for the therapist to note the mechanism of injury, and why, when, where, and how it occurred. The time of injury and onset to swelling and the area where swelling developed are also important. It is also important to note any feelings of weakness or instability along with past injuries in the same area.

In lateral ankle sprains, swelling will generally occur on the lateral side of the foot only and will make palpation often difficult. Ecchymosis may be present, however the blood will usually settle at the medial or lateral portion of the heel. Ankle active range of

motion should be assessed because Achilles tendon ruptures often mimic ankle sprains. Passive inversion of the ankle should reproduce the pain symptoms. Plantarflexion which stresses the AFTL will also exacerbate pain. It is also important to assess the arterial supply at the dorsalis pedis and posterior tibialis arteries. The sensation over the sural nerve distribution (lateral ankle region, heel, and lateral surface of the foot) as well as the lateral cutaneous branch of the superficial peroneal nerve (which innervates the peroneal muscles) should be tested. (98) Neuropraxias and palsies are not very common, however can be problematic if undiagnosed. One study in fact revealed that up to 80% of patients with severe ankle sprains have some peroneal nerve injury. (95)

Many individuals have complaints of functional instability after an ankle sprain. Common complaints include but are not limited to, difficulty running on uneven surfaces, difficulty in cutting and jumping in athletic events, feeling of giving way, recurrent pain, swelling, tenderness, instability, inability to run, and weakness. (95) Recurrent ankle sprains may be due to: healing of the ligaments in a lengthened position; weakness of the healed ligaments due to inherent weakness of the scar; peroneal muscle weakness; distal tibiofibular instability; hereditary hypermobility; loss of proprioception (especially due to peroneal nerve damage and damage to the mechanoreceptors and afferent nerve fibers present in the ligaments); impingement by the distal fascicle of the anteroinferior tibiofibular ligament; and/or impingement of capsular scar tissue in the talofibular joint. (95) It is important therefore to take a detailed history when attempting to diagnose when a person presents with chronic pain at the ankle. Generally if a person was able to run after he or she had an injury this is a good indicator that little to no instability is present.

While out of the scope of this paper, I do feel that it is important to note that historically grade III ankle sprains have been treated with surgery. Recent randomized controlled studies have shown however that better functional outcomes after acute ankle sprain are achieved with conservative treatment of functional and controlled mobilization rather than immobilization and while this does not ensure mechanical stability, most patients are asymptomatic at 12 weeks. (99, 100, 101, 102)

Traditionally standard AP, lateral and mortise views have been recommended in the cases of all ankle injuries to rule out occult fracture and osteochondral lesion. However, due to recent developments this is now not the case. The Ottawa Ankle Rules (94, 103), a set of rules designed to help determine which injuries to the ankle require radiographs, have assisted in reducing the number of unnecessary radiographs taken. These rules have been shown to be 100% sensitive, have a modest specificity (42.3%-77.1%), and in most cases can reduce the number of unnecessary radiographs by up to 40%. (103)

In brief, the Ottawa Ankle rules state that if a patient presents with bone tenderness in the posterior half of the lower 6 cm of the fibula or tibia or the base of the fifth metatarsal or over the navicular and the inability to bear weight both immediately and at the emergency room (provided the patient reports within the first 10 days after injury) then radiographs should be taken. If a patient presents more than 10 days after injury, including a work up for a persistently or increasingly painful ankle, then again the radiographs are warranted. (94, 103) The available research has shown that by following these guidelines, no significant fractures have been missed. (102)

Arthrography of the ankle, if performed within the first 24 to 96 hours, can allow visualization of ATFL and joint capsule ruptures in grade III sprains. Unfortunately however, because of prevalence of extravasation of dye into various tendons around the ankle this test has been considered unreliable diagnostically. (95) MRI is commonly used for diagnosis of chronic ankle sprains and is primarily useful for determining capsular thickening with ligamentous injuries. (95)

### **Sinus Tarsi Syndrome:**

Sinus Tarsi Syndrome (also known as Subtalar ligament sprain) is an overuse injury thought to be caused by microtrauma from excessive foot pronation. The sinus tarsi runs from the anterior inferior lateral malleolus posteromedially to just posterior to the medial malleolus. The Subtalar ligaments and connective tissue that are housed in this bony canal become painful, but often just anterior to the lateral malleolus. Because of this the

condition is often difficult to differentiate from a lateral ligament sprain except for stiffness at the Subtalar joint and pain in the area with palpation. (16)

### **Syndesmosis Injury:**

Also known as the high ankle sprain, syndesmosis injuries occur less frequently than lateral ankle sprains and involve disruption of the ligamentous structures between the distal fibula and tibia just proximal to the ankle joint. (96, 104, 105) It is reported that anywhere between 1% and 18% of all ankle sprain injuries also involve syndesmosis injury. (96, 104, 105)

The distal tibiofibular joint is comprised of three ligaments: the anterior inferior tibiofibular ligament (AITFL); the posterior inferior tibiofibular ligament (PITFL); and the interosseous ligament. The AITFL and the PITFL are considered the primary stabilizers of the distal tibiofibular articulation. (96) The AITFL and the PITFL act to constrain excessive distal fibular motion relative to the tibia and excessive external rotation of the foot on the leg. (96) In general, if the AITFL (which is weaker than the PITFL) is injured the interosseous ligament is injured as well. (96)

The interosseous ligament also acts as a buffer to axial tibial loading as it transfers a portion of the weightbearing load from the tibia to the fibula. (96) Disruption of this ligament may result in increased compressive stress within the tibia, increased likelihood of lateral dislocation of the distal fibula, and incongruence of the ankle joint articulating surfaces. (96)

Of importance to note is that the talus tends to act as a wedge in the ankle mortise when in extreme ranges of dorsiflexion. Because of this end range dorsiflexion may reproduce symptoms of pain because of the separation that occurs between the tibia and fibula when injury occurs. (96)

The typical proposed mechanisms of injury to the syndesmosis include: external rotation of the foot, eversion of the talus within the ankle mortise, and excessive dorsiflexion. (104, 105, 106) A detailed history including injury with external rotation of the ankle, special testing and diagnostic imaging (plain radiograph including a mortise view) (105) will assist in the diagnosis of this injury.

Common symptoms include tenderness with palpation to the AITFL, pain with active and passive external rotation of the foot, and pain with active and passive forced dorsiflexion. (96, 104) Clinical presentation will show a normal heel-toe gait pattern is often times replaced by a heel-raise gait pattern to avoid excessive ankle dorsiflexion. (96,104, 105) Swelling is not usually present with these injuries and isolated injury is rare, with injury generally being accompanied by injury to the deltoid ligament and fibular fracture. (96)

### **Plantar Fasciitis:**

The most common cause of rearfoot pain in runners is plantar fasciitis. Diagnosis is made clinically and individuals will present with gradual onset of pain in the inferior heel, which is worse in the first few steps in the morning or after rest. It may also worsen at the end of the day or after a run because of fatigue. Like other overuse injuries, symptoms are usually preceded by training errors. (106)

Upon physical examination, there is point tenderness over the anteromedial aspect of the heel at the medial process of the calcaneal tuberosity. A less painful, but still tender, area is along the plantar fascia, particularly the medial part. Symptoms are often worsened with passive dorsiflexion of the toes. (16)

Limited foot dorsiflexion is often also seen and often increases the risk for development of plantar fasciitis. In a study by Riddle et al., they found that limitations in dorsiflexion increased the odds exponentially. When individuals had only 6 to 8 degrees of dorsiflexion the odds ratio was 2.9, whereas those who had 0 degrees or less dorsiflexion had an odds ratio of 23.3. (107) Other risk factors include increased body mass, older age and excessive pronation and supination. (107)

Imaging is not needed, except to rule out other diagnoses. Often a heel spur is seen on radiograph which most likely is a result of increased forces that are caused by the tight fascia and abnormal biomechanics, and is not a cause of the pain. (86)

### **Fat Pad contusion and pain:**

Fat pad contusions and atrophy are another common cause of heel pain. Fat pad contusions are often caused when individuals run on rocky terrain, especially if wearing racing flats or spikes and or if the individual is a heavy heel striker at initial contact. Physical examination will reveal pain with palpation on the undersurface of the rearfoot. Assessing the individuals' footwear may show excessive heel strike during running gait cycle. Subjective exam should include questioning running surface typically run on and also any previous history of corticosteroid injection in that region as the corticosteroid may cause atrophy. Differential diagnosis will include calcaneal fracture and or heel spur. Diagnostic imaging will be negative.

### **Muscle:**

Muscle injuries are prevalent in sports with an incidence varying from 10% to 55% of all sustained injuries. Muscle injuries can be caused by contusion, strain, and or laceration. In running most muscle injuries are caused by an excessive force that overstrains the muscle myofibers and consequently causes rupture near the myotendinous junction. The majority of muscle strains occur in superficial muscles working across 2 joints such as in the case of the rectus femoris, semitendinosus, and the gastrocnemius/Achilles tendon. (108) Muscle injuries, unlike bone injuries, heal by a repair process not a regeneration process.

There are three phases to muscle healing: the destruction phase (characterized by the rupture and ensuing necrosis of the myofibers, the formation of hematoma and inflammatory cell reaction); the repair phase (characterized by phagocytosis of the necrotic tissue, the regeneration of myofibers, and the constant production of connective

tissue scar as well as capillary ingrowth into the injured area); and the remodeling phase (characterized by the maturation of the regenerated myofibers, the contraction and reorganization of the scar tissue, and the recovery of the functional capacity of the muscle.) (108)

Unfortunately, formation of the connective tissue scar can cause problems and delaying healing in an injured muscle. Immediately after an injury to muscle, a gap is formed between the ruptured muscle fibers and is filled with a hematoma. Within 24 hours phagocytes enter the hematoma and begin to dispose of the blood clot. Fibrin and fibronectin cross link to form early granulation tissue, an initial extracellular matrix that acts as a scaffold and anchorage site for the invading cells that will eventually restore the integrity of the connective tissue framework. (108) Of note is that recent findings show that the amount of intramuscular connective tissue is not increased in the injured skeletal muscle unless the muscle is completely immobilized for a substantial period of time. (108)

Early after trauma, the new connective tissue scar is the weakest link in the muscle, however approximately 10 days after the trauma the maturation of the scar has reached a point at which if loaded to failure, the adjacent muscle tissue would usually rupture first. This is not to say however that the muscle is completely restored to preinjury level; a relatively long time is still needed. (108)

Muscle strain and contusion injuries can be classified into three different types: mild (first degree) in which only a few muscle fibers are torn and only mild swelling and discomfort are present; moderate (second degree) in which greater muscle damage has occurred with a clear loss of function; and severe (third degree) is where a tear extends across the entire section of muscle and results in complete loss of muscle function. (108)

Diagnosing muscle injuries begins with a detailed history of the occurrence of trauma followed by examination of inspection and palpation of the muscles as well as functional testing of the muscles with and without external resistance. MRI has more recently

replaced ultrasonography as the leader in diagnosing muscle injuries, because of its accuracy in confirming/ruling out existence of muscle injury lesion. (108)

In general, “muscle injuries do heal conservatively” (108) and only rarely and in specific instances (large intramuscular hematoma or grade III strains or tears of the muscles) is surgery warranted. Most muscle injuries will heal within 3-5 days and if not, further diagnostic evaluation for the existence of hematoma or extensive tissue damage is warranted. (108)

### **Hip/Knee Region:**

The hamstrings, iliopsoas, rectus femoris, and adductor muscles may all be affected by strain injuries, with the proximal myotendinous junction of the biceps femoris being the most common site of injury. (82, 109)

Bicep Femoris muscle (hamstrings) injuries are very common in runners who perform a lot of sprinting. The hamstring muscle complex is a biarticular muscle group which works by flexing the knee and extending the hip. In everyday movements, flexion of the hip and knee occur together, with opposing effects on hamstring length. (110)

Most studies suggest that hamstring strains occur during the later part of the swing phase of running when the hamstrings are working to decelerate knee extension- that is the muscle develops tension while lengthening. This means that the hamstrings must change from functioning eccentrically, to decelerate knee extension in the late swing, to concentrically, becoming an active extensor of the hip joint. (110)

The most common non-modifiable risk factors in the literature for hamstring injury are older age and black or aboriginal ethnic origin. The most common modifiable factors are imbalance of muscular strength with a low hamstrings to quadriceps ratio (H:Q ratio), muscle fatigue, hamstring tightness, insufficient warm up and previous injury. (110)

The iliopsoas muscle acts a strong hip flexor and injuries usually occur near the muscle's insertion on the lesser trochanter of the femur. This muscle is typically injured during snow running or hill climbing. (39)

The rectus femoris muscle which extends the knee and flexes the hip is typically injured at the proximal muscular origin near the anterior inferior iliac spine (AIIS). This muscle is commonly injured during sprinting or jumping. (39)

Traumatic abduction or external rotation maneuvers may precipitate injuries of the adductor muscle group in that includes the pectineus, adductor brevis, adductor longus, adductor magnus, obturator externus and gracilis muscles. (39, 111) Hip adductor strains are often associated with lower hip adduction/abduction strength ratios and previous adductor injuries. (111)

### **Piriformis Syndrome:**

The piriformis muscle which originates by attaching to the anterior surface of the sacrum and sacrotuberous ligament inserts into the superior border of the greater trochanter of the femur. (5) The piriformis muscle most commonly rests on top of the sciatic nerve, however one particular study found that 12.2% of 640 limbs assessed had the common fibular (peroneal) division of the sciatic nerve running through the piriformis muscle and another 0.5 % the common fibular division passed superior to the piriformis muscle. (5)

Injuries to the piriformis muscle may cause the runner to present with numbness and tingling in the lower extremity, decreased hip range of motion, and pain with sitting and with walking or running. The pain will generally start in the buttock however may radiate to the low back and or lower leg depending on the severity of the damage to the muscle and the resulting pressure on the sciatic nerve. The runner will present with tenderness in the buttock region just inferior to the posteriosuperior iliac spine (PSIS) and continued on over to the greater trochanter of the femur. A lumbar spine screen should be performed to

rule out radicular pain symptoms coming from the origin of the sciatic nerve and referring to this area of the buttock and hip.

Appropriate timing of return to running should be determined by two simple measures: one is the ability to stretch the injured muscle as much as the healthy contralateral muscle and the second is pain-free use of the injured muscle in basic sport specific movements. (108)

### **Nerve:**

While nerve injury is not very common in runners, it can occur.

### **Hip:**

The ilioinguinal nerve, lateral femoral cutaneous nerve, and sciatic nerve (piriformis syndrome) are the most commonly compressed nerves in the hip and thigh region.

### **Knee:**

The common fibular (peroneal) nerve is the lateral and smaller division of the two terminal branches of the sciatic nerve. It is also the most commonly injured nerve in the lower limb. This is mainly due to the fact that it winds superficially around the neck of the fibula. Even when there is an injury to the sciatic nerve, its common fibular division is usually more severely affected than the tibial division. The common fibular nerve may be severely stretched subsequent to a rupture of the fibular collateral ligament. (5)

### **Ankle:**

The Tibial, Sural, and Common Peroneal nerves are the main nerves that innervate the ankle region and foot.

Diagnosis of nerve entrapment may be confirmed with needle electromyography and nerve conduction studies. (2)

### **Tarsal Tunnel Syndrome:**

This condition is caused by entrapment of the tibial nerve as it passes behind the medial malleolus. Often times this condition is caused after a trauma to the ankle rather than spontaneously or with overuse. However, excessive pronation at the rear foot may also cause the nerve to become irritated. Any or all of the branches of the tibial nerve may be involved. Individuals may present with deep aching pain and or paresthesias in the plantar surface of the foot. Symptoms will often worsen with running or at night and a Tinel's sign at the area of entrapment may be positive. (16) Pain may also be provoked with forceful active pronation or by sustained passive eversion. Intrinsic foot muscle wasting or weakness and sensory loss are uncommon with this condition; however a neurologic examination should be performed to rule out peripheral neuropathy or radiculopathy. Electrodiagnostic studies will confirm this diagnosis. (16)

### **Anterior Tarsal Tunnel Syndrome:**

This condition is caused by entrapment of the deep peroneal nerve as it passes under the extensor retinaculum. Individuals will present with aching and numbness on the dorsum of the midfoot, which can extend to the first web space. It is believed to be caused most commonly by poor fitting shoes especially if they are laced too tight. This condition may respond to changes in footwear or padding placed on the dorsum of the foot. (16)

### **Foot:**

#### **Interdigital Neuromas:**

Symptoms of this condition are caused by swelling of the nerves and scar tissue around the nerves. Individuals may develop this condition because of repetitive toe dorsiflexion that occurs at push off during running and excessive foot pronation. Individuals will

complain of numbness and pain in the toes that is worse with tight shoes and is weight is placed through the forefoot. The third metatarsal space is affected most commonly, so the third and fourth toes are numb most commonly. (106)

### **Compression of Medial Plantar Nerve (Jogger Nerve):**

As the medial plantar nerve runs through the master knot of Henry at the plantar medial aspect of the foot, it can become compressed. This neuropraxia causes symptoms of pain along the medial aspect of the foot radiating the great toe and occasionally to the ankle. Forefoot abduction, heel valgus, or overpronation can cause increased compression. Physical examination will reveal symptoms evoked by everting the heel or asking the individual to stand on the fall of the foot. A Tinel compression test is usually positive. (93)

### **Special Tests:**

#### **Hip:**

The Ober's test, used to determine ITB flexibility, is performed by having the examiner abduct and extend the individuals affected hip before allowing the thigh to adduct passively toward the midline. A positive test is noted when the thigh does not return to at least a neutral position or lateral hip pain is reproduced. (27)

The Modified Thomas Test, also used to determine ITB flexibility, is performed by having the individual bring both knees up to the chest while in supine. The individual then keeps the contralateral hip maximally flexed while the examiner slowly lowers the affected limb to the floor. (27) The test is positive if the leg does not return to the table.

The Noble Compression test may be used to determine ITB syndrome. This test is performed by having the individual lie on their side with the affected knee up and flexed to 90 degrees. The examiner then applies pressure to the ITB over the lateral femoral condyle while extending the knee. The test is positive if pain occurs as the knee

approaches 30 degrees of flexion, the position in which the tensed ITB rubs directly over the lateral femoral condyle. (112)

Femoral stretch testing is performed by passively bending the individual's knee then adding hip extension as a sensitizing maneuver. Like any dural tension test, the femoral stretch is considered positive if concordant symptoms are reproduced, worsens with dural tension tautness, and improves with dural tension slackening. (113)

Acetabular labral tears may be diagnosed by having the client bring the affected hip from a flexed, abducted and externally rotated position to an extended, adducted and internally rotated position which may reproduce the pain or clicking from an anterior labral tear. (114)

Moving an extended, abducted, and externally rotated hip into a flexed, adducted, and internally rotated position while applying a posterior load may reproduce pain in runners with a posterior labral tear. (115)

### **Knee:**

Hoffa's Test involves the examiner palpating the affected knee of the individual around the patellar tendon and then taking the knee from a flexed position to an extended position. A positive test is if the individual reports a sharp pain in the area being palpated. (59)

The Clarke's sign is a test used to identify the presence of chondromalacia of the patella. The individual lies relaxed with knees extended as the examiner presses down slightly proximal to the base of the patella with the web of their hand. The individual is then asked to contract the quadriceps muscle as the examiner applies more force. The test is positive if the individual cannot complete the contraction due to pain. (98)

The Hughston plica test is a test designed to determine an abnormal suprapatellar plica. The individual lies supine while the examiner flexes the knee and medially rotates the tibia with one arm and hand while with the other hand the patella is displaced medially with the fingers over the course of the plica. The test is positive if a “pop” is elicited at the plica as the knee is flexed and extended by the examiner. (98)

### **Ankle:**

The anterior drawer test estimates the stability of the ATFL. This test is performed by attempting to translate the foot anteriorly forward with respect to the leg by applying pressure at the heel. This test should be performed with the patient’s knee flexed.

Unfortunately this test performed early after an injury has limited reliability, particularly if negative, because of muscle guarding. It is typically believed that 4 mm of laxity (2 mm is normal) in the AFTL will give a clinically apparent anterior drawer. (95)

Interestingly enough, talar displacement of greater than 1 mm reduces the ankle’s weight bearing surface by 42.3%, thus creating asymmetric load-bearing of the articular surface. (95)

The inversion stress maneuver attempts to assess CFL integrity. In dorsiflexion the CFL is stressed so while the foot is dorsiflexed and the patient’s knee is bent, the examiner attempts to translate the calcaneus into inversion. This is also usually very difficult, if not completely impossible to perform in the acute stages of injury due to pain and swelling. If the ligament is completely torn instability may be obvious. (95)

The external rotation test stress test (Kleiger test) is performed with the patient in sitting. The examiner stabilizes the proximal leg with one hand and with the other hand applies an external rotation load to the foot with the ankle positioned in neutral. If positive, the external rotation will increase separation of the syndesmosis if injury present and will reproduce pain. (96)

The standing external rotation test requires a patient who is less symptomatic to stand on the affected leg and turn the pelvis (externally rotate the leg) to the opposite side. This test will again be positive for syndesmosis instability in the presence of reproduction of pain. (104)

The squeeze test is used to promote separation of the syndesmosis by the examiner gently squeezing the tibia and fibula proximal to the ankle joint. It is best advised to work from proximal to distal along the tibia and fibula making your way to the distal segment sequentially to avoid causing excessive pain in the injured patient. (96/104)

The point test (palpation test) is another test used to impose pressure on the anterior distal tibiofibular syndesmosis. The patient is either sitting or supine and pressure is applied directly over the anterior aspect of the syndesmosis. A positive test involves reported pain by the patient. (96)

The dorsiflexion maneuver forces the wider portion of the talar dome into the ankle mortise thereby inducing separation of the distal tibia and fibula. A positive sign is pain in the syndesmosis region. (96)

The dorsiflexion compression test involves patients in weightbearing moving their ankle joints into extreme dorsiflexion. Using an inclinometer the angle of the tibia is noted at which point the patient reports their pain is reproduced. The patient then assumes an upright position while the examiner places both hands around the distal tibia and fibula of the involved side. The examiner maintains the compression as the patient again moves into extreme dorsiflexion in weightbearing. A positive sign is if either pain is reduced with the compression or if an increase in dorsiflexion is noted. (96)

The one legged hop test is another test designed to determine syndesmosis injury. It is believed that patients with syndesmosis injuries are unable to complete 10 repetitions of unilateral hopping without significant pain. It has been suggested that this test is generally best saved for last and only if all other testing special testing is negative. (96)

Reliability data report that the external rotation stress test is more reliable than both the squeeze test and the dorsiflexion compression test. (94, 104) Some authors have also reported that patients with combined positive results for the external rotation stress and the dorsiflexion compression test took significantly longer time to return to competition. (108)

The navicular drop test in the foot is indicative of pes planus. For this test the navicular location is assessed in Subtalar neutral and then with weightbearing. A decrease of greater than 1.5 cm is considered to be significant pes planus. (113)

Two new tests have been proposed however reliability and validity have not been reported on yet. The first test is the cross-legged test. This test involves the patient sitting in a chair with the injured leg resting across the knee of the uninjured leg at about mid-calf range. The patient then applies a gentle force on the medial aspect of the knee of the test leg. A positive sign is reproduction of pain at the ankle syndesmosis. (96)

The second test is the heel bump test. This test is performed to force the talus into the mortise in an attempt to impose separation of the distal syndesmosis. To perform this test the patient sits on the edge of the exam table with the ankle resting in plantarflexion. The examiner then firmly grabs a hold of the involved leg with one hand and with the other hand provides a gentle but firm thump on the heel in an upward fashion, with their fist. A positive sign would be pain reproduced at the syndesmosis. Unfortunately this test may not be specific to Syndesmotoc injury because the test is also used to determine possible tibia stress fracture. (96)

### **Functional Clinical Outcomes Measures:**

Functional clinical outcomes measures for the lower extremity provide useful, objective information about the amount of function a patient has. While not necessarily useful for

diagnosing conditions, their information can assist with treatment design and allow for assessment of progress to be made.

The Western Ontario and McMaster Universities questionnaire (WOMAC) was developed for hip and knee OA studies. It has 24 questions and items are reported in three subscales (pain, stiffness and physical function). Each item is scored on a scale from 0-100 (with 100 being maximal limitation or symptoms) with a maximum score of 2400. (116) WOMAC has been reported to be the instrument of choice for individuals with hip and knee osteoarthritis.

The Lower Extremity Functional Scale (LEFS), designed to be used with a wide range of patients with lower extremity orthopaedic conditions, is based on the World Health Organization's (WHO) model of disability and handicap. There are 20 questions in the test and this test is scored out of 80 points. The higher the individual scores the less disability is perceived. This measure has been reported to be reliable and valid in patients with lower extremity musculoskeletal conditions and is more sensitive to change than the Short Form-36 (SF-36). (117, 118) A minimal detectable change score (MDC) of 8 points is required to reflect a true change in condition. (119)

Lysholm Knee Scale is a condition-specific outcome measure that contains eight domains: limp, locking, pain, stair-climbing, support, instability, swelling, and squatting. An overall score of 0 to 100 is calculated, with 95 to 100 indicating an excellent result; 84 to 94, a good result; 65 to 83, a fair result; and <65, a poor result. Originally designed to assess ligament injuries of the knee, the Lysholm knee scale has been used for a variety of knee conditions, including chondral disorders. In one particular study, the Lysholm knee scale demonstrated, in general, acceptable psychometric parameters (test-retest reliability, internal consistency, floor and ceiling effects, criterion validity, construct validity, and responsiveness) to justify its use in outcomes assessment for various chondral disorders of the knee. However, it may not be the optimal outcome instrument. (120)

The Anterior Knee Pain Scale (AKPS) is a self report measure made up of 13 questions. Activities including walking, stairs, squatting, running, jumping and prolonged sitting with knees flexed are included with areas such as pain, swelling, atrophy of thigh muscles, and limping among others to determine disability associated with anterior knee pain. Based on a score out of 100, the higher the individual scores the less perceived disability they have. This outcome measure has been determined to have good test-retest reliability and is responsive to change over time. A minimal detectable change score (MDC) of 14 points or greater is required to reflect a true change in the individuals condition. (119)

The American Orthopedic Foot and Ankle Scale was designed for use among all patients with foot or ankle dysfunction. (117) It comprises 4 region specific scales, including ankle-hindfoot, midfoot, hallux metatarsophalangeal, and lesser metatarsophalangeal scales. This outcomes measure has been used commonly in studies of foot and ankle surgical outcomes; however limitations have also been reported in its use. (117)

The Lower Extremity Functional Scale (LEFS), designed to be used with a wide range of patients with lower extremity orthopaedic conditions, is based on the World Health Organization's (WHO) model of disability and handicap. This measure has been reported to be reliable and valid in patients with lower extremity musculoskeletal conditions and is more sensitive to change than the Short Form-36 (SF-36). (117, 118)

The Foot and Ankle Disability Index (FADI) and Foot and Ankle Disability Index Sport (FADI Sport) are two other foot and ankle outcomes measures. The FADI was designed to be used among older populations or populations with limitations in the performance of activities of daily living. (117) Athletes typically reach a ceiling effect with this measure, scoring at the extreme high end of normal function.

The FADI Sport, which addresses activities like running, jumping and landing is reported to be more sensitive to detecting deficits in higher functioning individuals with chronic ankle instability. This outcome measure has also been shown to have moderate to good

reliability when used again for individuals with chronic ankle instability. (117)

Unfortunately this outcome measure too has limitations and may not be useful for populations without chronic ankle instability.

The Sports Ankle Rating System, a self report and clinician completed outcome measure which is used for individuals with suspected ankle sprains, demonstrated evidence for content and construct validity, reliability and responsiveness. (121)

Finally the Cumberland Ankle Instability Tool, a 9 item 30 point tool, was designed to measure severity of functional ankle instability. This measure has been reported to have concurrent validity with the LEFS and Visual Analog Scale (VAS). Construct validity and internal reliability were also reported to be acceptable. Sensitivity was 82.9% and specificity was 74.7% while Test-retest reliability was excellent (ICC=.96). (122)

### **Summary:**

Differential diagnosis for injuries in the leg is imperative so that runners can be diagnosed efficiently and effectively and so that there is minimal delay in return to sport. A thorough subjective history is needed and the examiner should ask common questions about adding mileage, footwear, frequency, and changing surfaces being run on as all of these factors can have an effect on overuse injuries in the lower extremity. It is also important to have the runner perform a dynamic evaluation as well as a static evaluation due to fact that many running injuries will not show up until the limb is being loaded. The use of special testing that is sensitive and specific is the hallmark of an expert clinician and minimizes false positives during examination. Also the use of functional outcomes measures is more than just helpful and all therapists should use them to assist in documenting outcomes.

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