Etiology, Treatment, and Prevention of Iliotibial Band Syndrome: A Literature Review

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ABSTRACT

Objective: This article provides an overview of the anatomy, biomechanics, causes, treatment, and prevention as it relates to iliotibial band syndrome. The effect of faulty biomechanics and how faulty biomechanics can cause an athlete to develop iliotibial band syndrome, will be discussed. Secondly, causes and preventative measures will be outlined. Finally, emphasis will be put on current treatment protocols backed by research examining and comparing different treatment options, and their ability to show partial or full resolution of iliotibial band syndrome following a given treatment.
Data Collection: A computer search using PubMed and Sports Science generated articles that were pertinent to the biomechanics behind the development of iliotibial band syndrome, prevention, causes, and treatment protocols. The information referenced in this review was generated using reviewed iliotibial band literature and numerous searches. Over 43 sources discussing the biomechanics as they relate to iliotibial band syndrome were located using PubMed and Sports Science. Another 155 articles were found that talk about the treatment of iliotibial band syndrome. One clinical review was found discussing biomechanical factors and treatment involved in iliotibial band syndrome. A second review was found, which speaks about the effectiveness of three different iliotibial band stretches.
Data Synthesis: One must take in to consideration numerous intrinsic and extrinsic factors when discussing the development of iliotibial band syndrome. Understanding the anatomy and biomechanics is fundamental when deciding the proper treatment for iliotibial band syndrome.
Conclusion: Hundreds of studies and reviews, including a few texts have promoted information on the development and treatment of iliotibial band syndrome. Evidence shows a variety of intrinsic and extrinsic factors can contribute to developing iliotibial band syndrome. Intrinsic factors can often be the result of weak or inhibited muscles, such as the gluteus maximus and gluteus minimus. If extrinsic factors are the problem, it is necessary to evaluate training habits, including shoe type and a rapid increase in mileage over a short period of time. Research has agreed that proper biomechanics may play the biggest role in prevention. Cyclists can help deter the development of iliotibial band syndrome by having a bike properly fit to the body type and frame, while both runners and cyclists opt to gradually increase mileage and frequency. More research is needed in the treatment of iliotibial band syndrome. Some research involving the effectiveness stretches are hindered, and this may be due to the inability to directly measure the iliotibial band. Treatment plans have been developed, but there needs to be more research that demonstrates their effectiveness. Rest has been determined as the best treatment, but an inclusion of different therapies has shown to accelerate the recovery process.

Key Indexing Terms: Treatment of iliotibial band syndrome, prevention of iliotibial band syndrome, biomechanics AND iliotibial band syndrome, correction of iliotibial band syndrome

Introduction

The iliotibial band is a longitudinal thickening of the lateral distal deep fascia latae and the superficial one quarter of the fibers of the gluteus maximus. The iliotibial tract originates from the proximal iliac crest and inserts on Gerdy's tubercle of the tibia as it passes over the lateral femoral epicondyle. The iliotibial band has several distal attachments, including biceps femoris, vastus lateralis, and the patella. Kaplan et al studied the dissections of one orangutan, three chimpanzees, one gorilla, one bear, and other four-legged animals, and concluded that although all quadruped animals have tensor fascia latae or gluteus maximus muscles, they do not all have an iliotibial band. Following the study, investigators determined that the iliotibial band is essential for erect posture. [1-7]

Iliotibial band syndrome is most often classified as an overuse condition, which is caused by the iliotibial band repetitively gliding over the lateral femoral epicondyle, and in turn inflammation arises secondary to friction. [1,2,3,8, 10] Friction is thought to occur as the knee is flexed past thirty degrees and the gluteus maximus pulls the iliotibial band posterior to rest atop the lateral femoral epicondyle. Furthermore, Orchard et al, describes the impingement zone to be at thirty degrees just following heel strike. The heel strike phase is also known as the deceleration phase, and during the weight acceptance portion of this phase the iliotibial band is eccentrically loaded, causing impingement. Iliotibial band syndrome is the most common cause of lateral knee pain in long distance runners, cyclists, and similar sports requiring repetitive knee flexion and extension. [1,2,3,8,9,11,12]

Athletes will frequently complain of pain of the lateral aspect of the knee, and it is often reproduced during the clinical examination. [1,2,3,8,9,11,12] However, the differential diagnosis for lateral knee pain includes degenerative joint disease, lateral meniscal tear, myofascial pain, lateral collateral ligament sprain, biceps femoris tendinopathy, popliteal tendinopathy, fracture, or referral from the lumbar spine, sacroiliac joint, or hip. [9,13] Regularly, patients with lateral knee pain will not be able to bend their knee past a certain degree, which results in an altered gait pattern. [9] The two most common orthopedic tests to rule in or out the diagnosis of iliotibial band syndrome are Ober's test and Nobles compression test. [1,2,3,12, 14] When the doctor performs Noble's compression test, the patient lies supine with the knee bent at ninety degrees, and pressure is applied to the lateral femoral epicondyle. [2,3,15,]

Ober's test is used to assess tightness of the iliotibial band, and the patient often presents with difficulty adducting the affected leg. As described by Gose and Schweizer, Ober's test is performed with the patient lying on their side with their affected side up, and the hip and knee are bent at a ninety degree angle, the examiner stabilizes the pelvis, and then abducts and extends the leg so that the iliotibial band is over or behind the greater trochanter, and then allow the thigh to adduct toward the patient's body. [2,17]

A positive Trendelenberg sign suggest weakness of the gluteus medius. Weakness of the gluteus medius results in compensation further altering lower extremity kinematics and aggravation of the iliotibial band. [3,18,19,20]

Patient's with iliotibial band syndrome often present with faulty biomechanics and/or anatomical factors. There are numerous anatomical factors that may contribute to iliotibial band syndrome including knee, forefoot, and rear foot alignments, Q-angle, iliotibial band tightness, and the size of the lateral femoral epicondyle. There are debates between various studies when considering the occurrence of iliotibial band syndrome in athletes with leg length discrepancies. When forces are increased and combined with genu valgum, excessive foot pronation, or leg length inequalities increased friction may occur. [1-,3, 21,22]

Many iliotibial band syndrome patients will show changes in lower extremity kinematics, for instance greater peak hip abduction, greater peak knee internal rotation, and femoral external rotation when compared to control groups. Along with that, the contribution of poor muscle performance, such as the hip abductors can further exacerbate faulty biomechanics. [1-,3,21-25]

A variety of altered biomechanical and anatomical factors, are often the basis for development of iliotibial band syndrome. This literature review will further discuss the many factors that may predispose an athlete to iliotibial band syndrome, and further evaluate the efficacy of treatment plans, protocols, and preventative measure that can be used in a clinical setting. The proper use of orthotics, well maintained hip abductor and adductor strength will be detailed. Along with that, Fredericson and Wolf developed a rehabilitative protocol for each stage of rehabilitation, and this protocol will be outlined in depth. The path of recovery may involve the correction of several contributing factors, consisting of weakness of the gluteus medius, excessive hip adduction and knee internal rotation, leg length discrepancies, and excessive knee varus and valgus strain. [1,2,3] Iliotibial band syndrome is a fairly common orthopedic condition, and when properly indentified and treated will frequently result in full recovery.

DISCUSSION

Anatomic Considerations

The iliotibial band functions as a lateral knee stabilizer, that arises off of the superficial one quarter of the fibers of the gluteus maximus and it continues as a longitudinal thickening of lateral distal deep fascia latae. This dense fibrous connective tissue goes from the anterior superior iliac spine, and has two distal insertion points, while being strongly anchored to the linea aspera of the femur, by way of its continuation with the lateral intermuscular septum. The first attachment site of the iliotibial band is at the upper edge of the lateral epicondyle of the distal femur by strong obliquely oriented fibrous strands. The iliotibial band resembles a tendon at the attachment site of the lateral femoral epicondyle, with a layer of adipose tissue beneath it. [1-3,7,16,26]

The adipose tissue is highly vascular and richly innervated containing pacinian corpuscles and myelinated and unmyelinated nerve fibers, which suggest this could be the site of inflammation that causes pain when compressed. [2,16]

Between the first attachment site at the lateral femoral epicondyle and the second attachment site on Gerdy tubercle of the tibia the iliotibial band appears to be ligamentous in structure and function. The Gerdy tubercle attachment site is tensed when the knee is in flexion and accompanied by tibial internal rotation during the weight acceptance phase of gait. [1-3,16,27,28]

Furthermore, the iliotibial band has other distal attachment sites, which include the patella via the lateral patellar retinaculum and epicondylopatellar ligament, biceps femoris, and vastus lateralis. As a group, they form an inverted "U," which gives anterolateral support to the knee (Figure 1). [7,16,27]

Fairclough et al describes in a study of 15 cadavers, six asymptomatic individuals, and two athletes experiencing iliotibial band syndrome that through magnetic resonance imaging and dissection no bursa was seen near the distal point of attachment. [16] In addition, Fairclough et al illustrates the injury as compression of the iliotibial band and Pacinian corpuscle containing adipose tissue on the lateral femoral epicondyle at thirty degrees of flexion with no anterior to posterior movement of the iliotibial band resulting in an inflammatory injury, rather than a friction injury. [2,16]

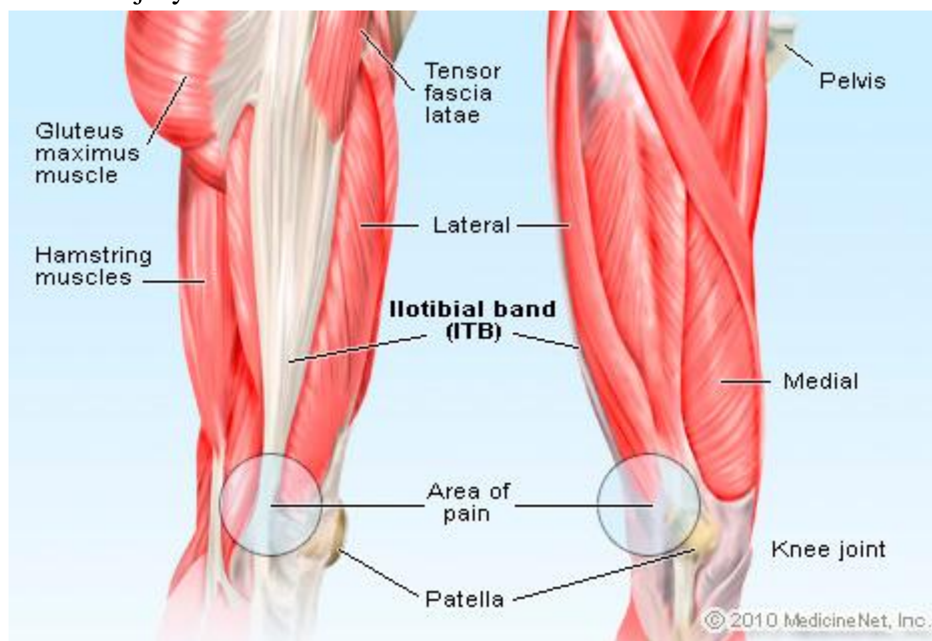

Figure 1 (**Picture of Iliotibial Band (ITB)**)

Biomechanics

With respect to the lateral femoral epicondyle, the iliotibial band continuously moves from anterior to posterior, as the knee flexes and extends during the running cycle. [1,29] The

proximal portion of the iliotibial band and tensor fascia latae helps maintain hip flexion in the swing phase, by moving anterior to the greater trochanter. In addition, as the hip extends for the duration of the stance and push-off phase, the proximal iliotibial band is pulled over the greater trochanter. Distally, the iliotibial band is pulled over the lateral femoral epicondyle, which helps maintain knee flexion, when the knee is flexed past thirty degrees. [1-3,7,30]

While in a static erect posture numerous muscles hold the iliotibial band in place. Proximally, the iliotibial band is posterior to the greater trochanter, this allows for the hip to remain in extension, with support from the gluteus maximus and tensor fascia latae. The iliotibial band is positioned anterior to the lateral femoral epicondyle, allowing the knee to stay in extension. [30]

Intrinsic Factors: Anatomical factors that could predispose an individual to increased friction over the greater trochanter and lateral femoral epicondyle include, knee, forefoot, and rear foot alignments, Q-angle, iliotibial band tightness, and the size of the lateral femoral epicondyle. [1-3,9,11,12,23,29,31,32]

In a recent study conducted by Ferber et al, his research suggests that female runners with greater peak hip adduction angle, and greater peak knee internal rotation were more likely to develop iliotibial band syndrome when compared to the controls. Using a retrospective design and control group comparison, the researchers hypothesized the iliotibial band syndrome control group would demonstrate greater stress at the knee due to internal rotation, and increased tensile stress at the hip in the frontal plane. [2,21]

Noehren et al performed a prospective study similar to Ferber et al. In which, Noehren et all analyzed female runners with iliotibial band syndrome, and contributing biomechanical factors, including knee internal rotation, hip adduction, and rear foot eversion angles. The researchers gathered data by way of three-dimensional bilateral analysis of lower extremity kinematics and kinetics. The investigators kept in contact with the subjects through e-mail over two years. The study's results revealed greater peak hip adduction, greater peak knee internal rotation angle, lower tibial internal rotation, and femoral external rotation when comparing the iliotibial band syndrome group to the control group. Noehren et al and Ferber et al research shows excessive hip adduction and knee internal rotation in female runner experiencing iliotibial band syndrome. [2,22]

A prospective study of iliotibial band strain was recently conducted by Hamill et al, in which he used interactive musculoskeletal software to determine iliotibial band strain, strain rate, and extent of impingement in female runners. Iliotibial band strain was calculated by taking the change in length during running divided by the resting length. Also, strain rate was measured by taking the change in strain divided by the change in time. Seventeen patients with iliotibial band strain and seventeen controls of the same age were studied. The investigators examined the experimental and control group's entire gait, while strongly emphasizing touch-down and peak knee flexion. When comparing the two groups' only strain rate was statiscally significant and this finding suggest strain rate may be a contributing factor in developing iliotibial band strain.[2,6]

Weakness of the hip abductors, mainly the gluteus medius, can result in a lateral pelvic tilt, and excessive strain of the iliotibial band. Fredericson et al. evaluated twenty four runners with iliotibial band strain, and the findings showed that all runners in the study had weakness of their hip abductors in the affected limb when compared to their unaffected limb and controls. Another study of fifty healthy marathon runners was performed by Stanford University Biomotion Lab evaluating peak hip adduction. The runners were followed throughout their training season, and seven of the runners developed iliotibial band syndrome. The results of the study showed that all seven runners had increased peak hip adduction. The study performed by Stanford University Biomotion Lab, further shows that decreased control of the hip adductors will results in an inability to properly control hip adduction through the gait cycle, thus increasing strain on the iliotibial band. [2,24]

In continuation, weak hip abductors may also contribute to increased torque at the knee. Noehren et al. established that iliotibial band injured runners have increased internal tibial rotation when compared to the controls. In return, further strain is put on the iliotibial band with increased pressure distally over the lateral femoral epicondyle. [1,6,22]

Along with that, a ground reaction force diagram is a one way to visualize the relationship between the hip and knee in the frontal plane. Powers gives a biomechanical perspective of these frontal plane movements during a normal single-limb stance, and two possible disturbances that can affect normal single-limb stance. While in a normal single-limb stance, the ground reaction force vector may pass medial to the knee joint and produce varus torque at the knee. In some cases, such as ones with excessive hip adduction the ground reaction forces may pass more medial, with a large perpendicular distance to the knee joint. The consequences are a positive Trendelenburg sign (lateral pelvic tilt), elongated lateral hip musculature, and increased varus torque at the knee. Thirdly, one may develop a compensated Trendelenburg sign where the ground reaction force vector passes lateral to the knee causing valgus stress accompanied by increased hip adduction (Figure 2). [2,33]

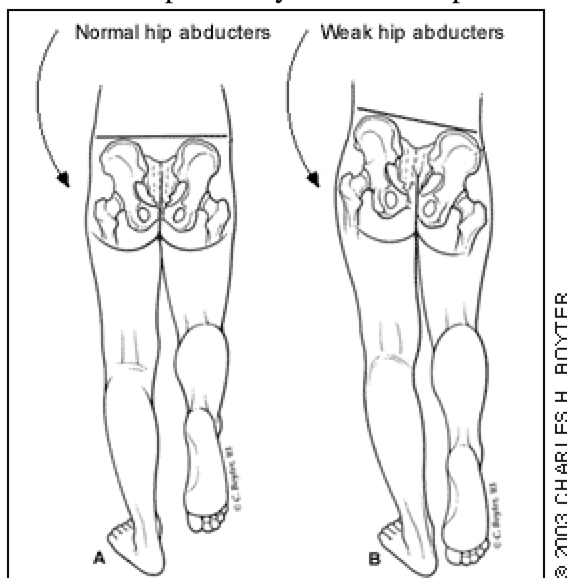

Figure 2

As stated previously, Noehren et al. study on the lower extremity biomechanics of female runners who eventually develop iliotibial band syndrome may also have abnormal mechanics at the foot and tibia. His primary findings were excessive hip adduction and knee internal rotation, but he also identified four subjects that also had unwarranted amount of calcaneal eversion. [22] On the contrary, a study presented by Messier et al showed no significant difference in calcaneal eversion when comparing the control and experimental groups. [2]

A study conducted by Bauer and Duke et al examined twenty injured and twenty healthy individuals. Their research looked at the comparisons between health and injured anatomical and lower extremity running kinematics. They hypothesized that individuals with iliotibial band syndrome would have a larger leg length discrepancy and different running kinematics than healthy runners. All participants were between eighteen and fifty-five years old, and must have ran at least thirteen kilometers over the past year. Runners were asked to fill out a running questionnaire asking for preferred running surfaces, incorporation of other athletics such as swimming, weightlifting, bicycling, stair masters, and stadium steps, and when a subject decided to change running shoes, which included every 4-12 or every 200-600 miles. The study's results demonstrated no difference in knee flexion angle at initial contact, tibial rotation in stance deceleration, or maximum tibial rotation in stance, when comparing runners with or without a leg length deficiency. Also, fifty six percent of runners in this study experienced iliotibial band syndrome in the shorter leg rather than the longer leg. [1] In contrast, McNicol et al examined fifty two cases of iliotibial band syndrome and found that thirteen percent had leg length inequalities, and of these thirteen percent all runners had the injury on the long leg side. [1,32]

Miller et al conducted a study to evaluate the lower extremity biomechanics during an exhaustive run. His study included sixteen runner, eight with iliotibial band syndrome, and eight age-matched controls. His results, further clarify that runners with iliotibial band syndrome will demonstrate increased maximum foot inversion, maximum knee flexion at heel strike, and maximum knee internal rotation velocity. [2,34] Collectively, the results of the previous spoken studies show that along with excessive hip adduction and increased internal tibial rotation, abnormal foot and ankle biomechanics can play a role in developing iliotibial band syndrome.

Extrinsic Factors: Development of iliotibial band syndrome correlates with numerous training factors, including a rapid increase in weekly mileage, excessive running in the same direction on a track, and running downhill because there is increased friction between the iliotibial band and lateral femoral epicondyle due to decreased knee flexion at foot strike. [3,23,35,36] Orchard et al suggest that sprinting may help to prevent iliotibial band syndrome because there is greater knee flexion meaning less time is spent in the impingement zone. The author implies that downhill and slow running contribute to the development of iliotibial band syndrome. [3,9] On the other hand, Miller et al discounted Orchard et al theory, when he found that during exhaustive run, runners with a history of iliotibial band syndrome will experience greater knee flexion during heel strike. [34] Furthermore, extrinsic factors include type of running shoe and cycle fit.

[2,9,23] Further research needs to be conducted on the topic, since there are no available studies that evaluate iliotibial band strain and sprinting.

Farrell et al analyzed kinetic data in relation to cycling kinematics, and compared the data to values for running. Ten non-injured cyclists were evaluated with motion analysis and synchronized foot-pedal forces. At the conclusion of the study it was determined that cycling had a lower pedal reaction force of 17-19% when compared to running, and cyclists also experienced 38ms in the impingement zone, where as runner spend about 75ms in the impingement zone. However, when investigators evaluated a one and half hour bike ride to a ten kilometer run, cycling produced more repetitions, thus they experienced more repetitive stress than runners.[38]

A theory developed by Farrell et al proposes that when the shorter leg is fixed to a pedal, the leg is overstretched laterally and functions in less knee flexion, thereby increasing the time spent in the impingement zone. [38]

Prevention

Runners and cyclist should train on level ground every other day. [2,5] Runners and cyclist should monitor themselves for reoccurrence of symptoms, while gradually increasing distance and frequency. [3] Combining cross training activities such as hill running, track running, swimming, and cycling is not recommended owing to repetitive knee flexion throughout the impingement zone.[2,9,23] Orthotics should be considered if your patient is a runner experiencing unwarranted calcaneal eversion and tibia internal rotation when performing functional tasks or they have an anatomical leg length deficiency of 0.5cm or greater. [3,32,37]

Cyclist suffer from repetitive flexion through the impingement zone and toe-in position, therefore it is advisable to check bicycles for proper fit. [3,38] In order reduce passive stretching of the gluteus maximus and iliotibial band; Wanich et al suggest lowering the seat beyond the typical height allowing for less knee extension and stress on the iliotibial band. It is also recommend evaluating cleat position, and determining if orthotics is necessary to prevent excessive tibial rotation and foot hyperpronation. Flexibility of the hamstrings and gastroc-soleus muscles are emphasized with some importance placed on flexibility of the gluteus maximus and iliotibial band. [2,39] Holmes et al treated 61 cyclists suffering from iliotibial band syndrome by modifying their training programs. Investigators adjusted the bikes to best resemble the cyclists normal off-bicycle alignment, but lowered the seat causing the knee to flex between thirty and thirty-two degrees at the bottom center of the pedaling stroke. Other training modifications included flat terrains, controlled mileage, easy pedaling at 80 revolutions per minute, and pain free. [2,39]

Clinical Presentation

Subjectively, the chief complaint by patients in a study performed by Sutker et al was lateral knee pain during exercises involving repetitive knee flexion and extension while being put under a load, as seen in the deceleration phase of running. In the following study, Sutker et al diagnosed forty eight cases of iliotibial band syndrome following the evaluation of 1030 runner complaining of lower extremity pain. Diagnosis of the forty eight cases of iliotibial band syndrome was concluded upon pain consistent with the patient's history and localized tenderness over the lateral femoral epicondyle. However, patients were able to hop and squat without pain. [40]

In an article written by Khaund and Flynn they describe a clinical presentation of diffuse lateral thigh pain, with sharp discomfort of the lateral femoral epicondyle and/or lateral tibial tubercle. They expand on this by stating patients may experience pain at the completion of a run or even a few moments into a run and throughout a run irritation will gradually increase. Along with that, patients will often put in their history that they notice an exacerbation of their symptoms while lengthening their stride or sitting for long periods of time with their knees in flexion.[13] In comparison to the article written by Khaund and Flynn, Fredericson and Wolf show patients to have a history consistent with symptoms developing after a reproducible time and distance, and typically begin runs pain free. They also note that patients often mention pain with lengthening their stride and sitting with their knees flexed for long time periods. In addition, patients will bring up pain while running down hill, and in severe cases pain while walking or going down stairs. [3]

An assessment of cases by Renne, military recruits with iliotibial band syndrome showed a limp accompanied by a straight leg gait, which contraindicates Sutker's patient's ability to hop and squat pain free. She further notes, symptoms were aggravated with runs greater than two miles and hikes consisting of ten miles or more. [11]

In various studies results have shown patients mention several training factors, which correlate with the development of iliotibial band syndrome. McNicol et al found that forty two percent of fifty two subjects with iliotibial band syndrome developed it through errors in training. Training errors included seven cases of a rapid increase in the amount of training, one case was due to over exposure to hills while running, four cases of improper footwear and surface issues, two cases of hurried initiation, and twelve cases of a single rigorous training session. [1,2,32] Messier et al obtained similar results when he evaluated forty eight cases of iliotibial band syndrome, and found that patients experiencing iliotibial band syndrome had less experience and had recently increased their training mileage when compared to seventy controls. [23] In conclusion, the clinical presentation of iliotibial band syndrome is consistent with pain along the lateral thigh, associated with excessive training, and aggravated by running while experiencing iliotibial band syndrome, and other sports involving repetitive knee flexion and extension.

Physical Examination

Upon palpation, patients with iliotibial band syndrome will most commonly experience tenderness and discomfort two centimeters above the joint line, and the discomfort is typically exacerbated when the knee is bent at thirty degrees of flexion. Less commonly, tenderness maybe palpitated at the lateral joint line, popliteal tendon, lateral collateral ligament, or anterior lateral fat pad. The affected area may also present with pitting edema, crepitation, or snapping. At the angle an angle of thirty degrees, the iliotibial band is at maximum tension, thus provoking the patient's symptoms. Furthermore, Khaund and Flynn make mention of possible findings, including multiple trigger points located in the vastus lateralis, gluteus medius and biceps femoris, which refer pain to the lateral aspect of the affected knee. The examiner should also check for the appropriate strength in hip abductors, knee flexors, and knee extensors. [2,3,13,15]

There are two common orthopedic tests used to objectively examine a patient. The first of the two is Noble compression test (figure 3). When performing Noble compression, the examiner should be able to reproduce the symptoms with compression of the lateral femoral epicondyle while the knee is bent at thirty degrees. However, while performing the examination the patient's knee is bent at ninety degrees, and the examiner extends the knee while applying pressure just proximal to the lateral femoral epicondyle. In a cadaveric study performed by Orchard et al and Fairclough et al on separate occasions, both studies showed an impingement zone at thirty degrees of flexion. Being able to properly identify the impingement zone allows the examiner to determine if the patient is suffering from iliotibial band syndrome or various other disorders, such as injury to the lateral meniscus, lateral retinaculum, popliteus and biceps femoris tendons, patellofemoral joint, and lateral collateral ligaments. [2,9,16]

In connection with Noble compression, Ober's test (figure 4) is most often used to examine iliotibial band tightness.[2,3,17] As described by, Gose and Schweizer Ober's test is performed by: (1) positioning the patient on their side with the affected leg up (2) the examiner then flexes the knee to ninety degrees while stabilizing the pelvis, the hip is positioned in a flexed and abducted posture (3) Put the hip in to extension allowing the iliotibial band to slide over or behind the greater trochanter (4) When the affected leg is lowered and adducts without pain, it is concluded that the patient does not have iliotibial band syndrome. In the case that the leg remains in abduction the authors details iliotibial band restrictions as: (a) minimal (adducted to the horizontal but not fully to the table), (b) moderate (adducted to the horizontal), and (c) maximal (patient is unable to adduct to horizontal). [2,17] In continuation, the patient may or may not experience pain, with the primary indicator of the Ober's test being that the affected leg remains in abduction. In addition, if a patient does experience pain this is the result of excessive friction over the lateral epicondyle while the knee is being flexed and extended. [13]

Figure 3

Figure 4 kneeguru.co.uk

In relation to Ober's test, it is recommended to use the modified Thomas test because both can adequately evaluate hip extension, and decreased flexibility of the tensor fascia lata, iliotibial band, iliopsoas, and rectus femoris. [3,5] The modified Thomas test is performed by having the patient sit close to the edge of a treatment table, holding their thigh to their chest, and rolling on to their back, as the opposite leg hangs off the table. Clapis et al conducted a study measuring subject's joint ranges using a goniometer and inclinometer while performing the modified Thomas test. Clapis et al performed the study on forty-two non injured subjects, all subjects were measured with a flat lordosis, which was palpated while measurements were performed, and the patient also maintained a neutral hip during the exam. The instruments were placed proximally at the midline of the pelvis and distally at the midline of the femur distally, and results showed interclass correlation measurements using the goniometer to be 0.92 and when using the inclinometer interclass measurements was 0.89. [2,41] Along with that, Harvey had 117 elite athletes in sports including tennis, running, rowing, and basketball perform the modified Thomas test. In this study interclass correlation was .91-.94 respectively. [2,42] Harvey's findings were (1) psoas averaged -11.9 degrees (below the horizontal), (2) quadriceps was 52.5 degrees, and (3) tensor fascia lata-iliotibial band average 15.6 degrees of abduction. [2,42]

Associated with iliotibial band tightness is lessened flexibility. Due to biomechanical factors associated with iliotibial band syndrome the muscles that support the hip laterally should be assessed for flexibility. [2,3] Decreased flexibility has been known to be a causative factor of iliotibial band syndrome. Frederickson et al proposed benefits to stretching by reducing the tension of the iliotibial band, with the ability to alleviate myofascial trigger points and fascial adhesions found in patients experiencing iliotibial band syndrome. [2,3,43] In contrast, Messier et al examined stretching routines in fifty-six runners with iliotibial band syndrome, and seventy controls, and his results showed no differences between the two groups.[2,23]

Furthermore, examination of the gastrocnemius and soleus muscles should be checked for flexibility. In the case, that these two muscles are tight the end result is decreased ankle dorsiflexion, which results in both excessive ankle pronation and knee flexion. Other causes of

increased ankle pronation consist of pes planus, compensation for a forefoot varus, metatarsus adductus or femoral or tibial torsion, all of which may contribute to iliotibial band syndrome. Pes planus contributes to iliotibial band syndrome by increasing internal rotation hop the leg and thigh, as well as exposing underlying conditions like weakness of hip abductors and hip external rotators. [1,3]

Previously mentioned in the above section, Bauer and Duke et al performed a study examining leg length discrepancies in correlation with iliotibial band syndrome. Results showed a relationship between leg length inequality, but subsequent studies cannot show whether iliotibial band is more common in the longer or shorter leg. [1] Accordingly, McNicol et al analyzed fifty-two patients with leg length inequalities, thirteen percent had iliotibial band syndrome, and of thirteen percent of those subjects showed iliotibial band syndrome on the long leg side. [32] Whereas, Bauer and Duke et al showed fifty percent of their patients to have iliotibial band syndrome in the shorter leg, at the conclusion of their study.[1] With that being said, leg length discrepancies are a causative factor of iliotibial band syndrome, and should be monitored and treated in coordination with iliotibial band syndrome. However, in order to properly treat iliotibial band syndrome caused by a short leg the examiner must first determine if it is a functional or anatomical short leg. [3] If the patient has a true leg deficiency of greater than 1cm, a heel lift is recommended. [3,35,36,44]

Additionally, excessive friction caused by the iliotibial band rubbing over the lateral femoral condyle, may be intensified directly or indirectly due to myofascial restrictions. [3] These restrictions may arises in the forms of trigger points, muscle contractures, or facial adhesions, and may be the direct cause of lateral knee pain or develop indirectly due to iliotibial band syndrome with the subsequent result of excessive tension on the iliotibial band. [5] In order to confirm trigger points, the doctor must use firm pressure in the area/s of the complaint, which are most frequently located in the vastus lateralis, gluteus minimus, piriformis, and distal biceps femoris muscle, and these trigger point often result in referred pain to the lateral thigh, knee, and sometimes the lower leg. [3,46] The examination is best performed with the patient lying on their side, their affected hip bent at forty five degrees and the knee slightly flexed with a pillow under the leg being palpated. In addition, if myofascial restrictions are found, myofascial treatment is indicated, whether there is pain referral or not, but no myofascial treatment is indicated if there is no evidence of contracture, sensitivity, or referral. [3]

Lastly, strength tests are a crucial step in determining if the hip abductors are properly functioning, and not the primary cause for the development of iliotibial band syndrome. If during the examination the doctor discovers weakness or inhibition of the gluteus medius, the doctor must further investigate this in order to determine if a patient has developed compensation and improper firing of muscles. Improper firing may result in a patient substituting the gluteus medius for the tensor fascia-latae, quadratus lumborum, or both. Hip abduction can be achieved with flexion and internal rotation of the hip if the compensation is a result of improper firing of the tensor fascia-latae. Upon further examination, the doctor may also note excessive hip hiking due to over-activation of the quadratus lumborum. The correct firing pattern would begin with

activation of the gluteus medius, followed by the tensor fascia-latae and ipsilateral quadratus lumborum and erector spinae.[3]

EMG is a viable way of detecting muscle imbalance between the tensor fascia lata and the gluteus medius and maximus. [2] As described by Kendall et al, the tensor fascia lata may substitute for the posterior fibers of the gluteus medius and the hamstrings may substitute for the gluteus maximus. [2,47] Functional tests allow for assessment of trunk and lower extremity strength, including signs of excessive femur internal rotation, ipsilateral hip adduction, and contralateral hip drop while performing the Trendelenburg test (figure 2). [2,18-20] Yet there is dispute on whether or not one can determine if the weakness arises from the core stabilizers or hip musculature. [2,18,20]

Gary Gray, a physical therapist describes several functional tests for evaluation of hip abductor strength. These tests include the single-leg balance, anterior-ipsilateral reach test (figure 5), and this causes the foot to pronate resulting in hip and lower extremity internal rotation, thus allowing the doctor to assess gluteal strength and range of motion in the sagittal and transverse planes. [3,48] Fredericson and Wolff further assessed this by using a measuring pole and measuring tape to see how low patients could go, and how far they could reach. By measuring how far a patient could reach and how low they could go gave Fredrickson and Wolff the opportunity to examine the patient's ability to pronate their foot and the ability of the entire lower extremity to decelerate motion, examining both sides for fluidity and symmetry of both motion and total distance. [3]

Fredericson and Wolff further examined the patients by having them perform single leg balance, frontal-plane overhead reach test (figure 6). This gives the examiner the ability to examine the lateral gluteal region and its' ability to decelerate motion in the frontal plane. [3] The frontal plane is mainly controlled by the gluteus maximus, and the gluteus maximus also influences concentric femur external rotation and eccentric femur internal rotation. [2,47,49,50]

When performing the frontal-plane overhead reach test Fredericson and Wolff had the patients stand 51-61 cm from the wall at a right angle, and then the patient will reach overhead using the arm furthest from the wall while the doctor examines fluidity and symmetry of motion in the frontal plane. In order to determine if a patient has tight lateral gluteal muscles caused by hip tightness in the frontal plane, the doctor will look for excessive lateral flexion of the torso. If a patient is able to pass this functional test the doctor will continue to have the patient perform the test moving them further from the wall until a threshold is met. Examining and determining if a patient has iliotibial band syndrome can be a relatively simple and effective process, but exclusion of many variables including leg length inequality, flexibility, and strength is key. [3]

A second functional test for the gluteus maximus requires the patient to be prone with the knees flexed to ninety degrees with neutral rotation. While in this position the doctor applies pressure to the lower portion of the posterior femur. The patient should have equal strength bilaterally and should be able to fully resist without a break. [2,47,49]

Figure 5 blog.naver.com Figure 6 ptonthenet.com

Treatment and Rehabilitation

Frederickson and Wolf have researched and produced an extensive treatment protocol, which focuses specifically on the treatment and rehabilitation of runners who have developed iliotibial band syndrome. Fredrickson and Wolff have divided treatment and rehabilitation in to four separate categories consisting of an acute phase, subacute phase, recovery strengthening phase, and return to running phase.

Acute Phase: according to these authors, in the acute phase the primary goal is to reduce local inflammation over the lateral femoral epicondyle caused by iliotibial band friction. Oral nonsteroidal anti-inflammatory drugs have been shown to be effective in reducing pain and inflammation. The use of modalities such as ice massages, phonophoresis, or iontophoresis have also been beneficial in reducing pain and inflammation. However, without modification of activities these treatments are ineffective. Any activity with repetitive knee flexion including running and cycling should be avoided in order to decrease stress at the lateral femoral epicondyle. In some instances all a runner needs to do discontinue running downhill or running in the same direction. With patients who have iliotibial band syndrome, the only recommended exercise is swimming only using their arms with a pool buoy between their legs. If after three days of treatment, there is still visible swelling a local corticosteroid injection might be recommended, as it is helpful in reducing local inflammation. [2,3]

Subacute Phase: Following the reduction of inflammation patients may begin a series of iliotibial band focused stretches with a goal of lengthening the iliotibial band. If the lateral gluteal muscles are found to be weak or are functioning improperly other muscles including the iliotibial band will compensate causing contraction of the iliotibial band. [3,52] Therefore, it is recommended to perform contraction-relaxation stretches allowing relative lengthening of the shortened muscle groups. These exercises are performed in sets of three, consisting of a seven second submaximal contraction followed by a fifteen second stretch, with the individual’s main

focus on lengthening the iliotibial band and tensor fascia-latae. When performing the standing stretch, the patient stands upright, using a wall if needed. The symptomatic leg is extended and adducted over top of the uninvolved leg. The patient exhales and slowly flexes the trunk opposite the side of the crossed leg until a stretch is felt on the side of the hip. On the side being stretched, it is essential that the foot reaches optimal pronation, which allows the hip to fully load eccentrically. The area being stretched can be varied, by extending or tucking the pelvis. Placing the arms overhead during the standing stretch can accentuate the stretch by increasing lateral trunk flexion. The patient may reach out with extended arms and clasped hands while bending downward, allowing for a stretch in the transverse plane (figure 6). [2,3]

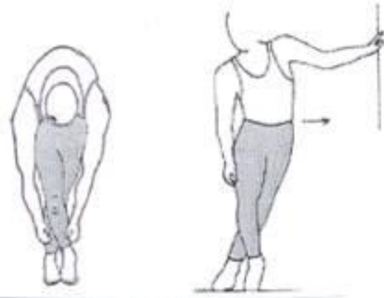

Figure 6 pamf.org

During the subacute phase and after the acute inflammation subsides, it is necessary to address myofascial restrictions. This is complimentary to physical therapy, and any restrictions should be attended to prior to muscle strengthening and re-education. Frequently, soft tissue treatment decreases pain and definitively treats the condition. The use of a foam roller on the tight muscles is also beneficial. [3]

In reference to the stretches recommended during the subacute phase, Fredericson et al conducted research at the Stanford Biomotion Lab, in which he evaluated the relative effectiveness of three iliotibial band stretches. Prior studies have not gotten adequate results due to human measurement error, but the following study eliminates these errors by using a new system developed by the Biomotion Laboratory, which evaluates the effectiveness of each stretch. The subject's biomechanics were captured as three-dimensional images during the study using a four camera gait acquisition system with a forceplate. Each stretch was measured for change in iliotibial band tissue length and the force generated within the stretched complex. The data was combined and analyzed by using kinetic value assessment. By evaluating the end point of a stretch to an upright standard, tissue length change was measured. The forces generated were measured as the net torque about the hip and knee centers, which were represented by using the external adduction moments about the hip and knee. The study assumes that the most effective stretch will increase the length of the tissue and overcome the external moments of the lateral complex. [3,43]

The three stretches were standing stretches that can be performed without the assistance of an aid. The following stretches were chosen for their common usage, ease of implementation, and prescription. In the standing position, the participant was instructed to extend and adduct the

leg being stretched across their other leg. The subject exhales, and slowly laterally flexes the trunk to the opposite side until a stretch is felt around the area of the greater trochanter. Stretch B is similar to stretch A, but the subjects hands are clasped overhead, while laterally flexing the trunk and stretching the arm on the same side as the leg being stretched. Stretch C begins like stretch B with the arms over head, but in stretch C the subjects bend diagonally downward. [3,43]

All five subjects were elite-level male distance runners, who denied ever having a lower-leg injury or surgery that prevented them from participating in a competitive season and each participant performed the stretches in a different sequence to prevent a warm-up phenomenon. The study tested all athletes at the same time of the day before their afternoon workouts, in order to minimize measurement error. X, Y, Z coordinates of six retroreflective markers were placed on lower body landmarks, and were captured using a four-camera system. Lateral markers included the iliac crest, greater trochanter, and lateral midline of the knee. Along with three markers placed on the lateral malleolus, lateral calcaneous, and fifth metatarsal. Hip and knee moments were calculated as a product of the ground reaction vector (Newtons) and the moment arm (meters) to the center of the knee and femoral head, and all moments were normalized using each subject's height and weight. The subject's were given instructions, and were told to stretch until they felt a "good" stretch, and hold the stretch for thirty seconds, and during the last 5 seconds of the stretch data was collected. Each subject performed 3 repetitions of each stretch, and each series of stretches that the subject performed was averaged and calculated for the average iliotibial band length and relevant moments. Pairwise 2-tailed Student *t* tests were used to compare average measures for each stretch, with statistical significance defined as a *P* value less than .05. [43]

Results showed all three stretches to be statistically significant, but stretch B was the most effective and most consistent when comparing average adduction moment at the hip and knee and in average iliotibial band length change. Between all three stretches a statistical significance was found in iliotibial band length ($P<.05$). Stretch B increased the length of the iliotibial band by an average of 11.15%, while stretch A lengthened the iliotibial band the least averaging 9.84%. There was not statistical significance between A and B or A and C when evaluating averaging adduction moments at the hip and knee. However, there was statistical significance between B and C when comparing average adduction moments at the hip and knee ($P<.05$). [43]

The study discusses that due to myofascial trigger points, hip abductor muscle inhibition, and fascial adhesions cause increased tension on the iliotibial band, and therefore a stretching protocol should be included in a patient's treatment plan. This helps the tissue return to their functional tissue length and decrease iliotibial band tension. Using the Biomotion Laboratory system, the study found that extending the arms overhead with increased lateral flexion improves the overall effectiveness of the standing iliotibial band stretch, and are simple enough to be implemented in to a clinical setting. The results suggest that there is a 1-2% difference that is physiologically detectable. [43]

In conclusion of this study, the use of Biomotion Laboratory systems clinically significant data was able to be obtained. The studies use of advanced methods, determined that adding over-head arm extension to the average iliotibial band stretch, produced statistically significant difference in iliotibial band length. However, there was no direct measurement of the iliotibial band, which suggests the gluteals, tensor fascia lata, vastus lateralis could have contributed to the changes. Overall the studies errors were minimized by the use of Stanford's Biomotion Laboratory, comparisons were between individuals lowering the possibility of systematic errors, stretching was static preventing skin motion errors, and markers were placed by a highly trained staff. [43]

Recovery Strengthening Phase: Following the subacute phase, and resolution of all myofascial restrictions, trigger points, and full rang-of-motion is established, the recovery strengthening phase may begin. For all exercises, it is recommended to start with five to eight repetitions and gradually build to two to three sets of fifteen repetitions, being sure to perform the exercises bilaterally even if only one leg is symptomatic. Previous articles with inclusion from Fredericson et al focused on concentric side-lying leg lifts that then progress to single-leg balance, step downs, and pelvic drop exercises. [3] The majority of these exercises focus on strengthening the gluteus medius and maximus. [2]

EMG studies have guided therapeutic exercises programs, by showing activation of the gluteal muscles. Distefano et al conducted a study evaluating maximal voluntary isometric contraction in 21 healthy subjects, who performed open and closed chain exercises focusing on the gluteus medius and gluteus maximus. Specific positions that encourage gluteal recruitment were chosen, and include vertical tibia with lunging and forward trunk by hip flexion with squat activity. Comparable exercises included clam shell, lateral band walks, side-lying hip abduction, single-limb squats, single-limb dead lift, multiplanar lunges, and multiplanar hops. The ICC for all exercises previously mentioned, except for multiplanar hops, were 0.85-0.98 for gluteus maximus and 0.93-0.98 for gluteus medius. The requirement for a strengthening exercise proposed by the investigators was 60% or greater normalized EMG during maximal voluntary isometric contraction. The sing-limb dead lift caused the greatest activation of the gluteus maximus, but maximal voluntary isometric contraction only reached 59%. The gluteus medius demonstrated 61% activity during lateral band walk, which increased to 64% when performing a single- limb squat. In addition, side-lying hip abduction produced the greatest contraction of the gluteus medius displaying 81% activity. [2,53] In comparison, the clam shell without a resistance band only obtained 38-40% activation. This study used EMG patterns to support the use functional-based exercises and open chain resistance exercises to strengthen gluteal muscles. [53]

Fischer and Houtz et al proposed that the position of the trunk and degree of knee flexion may change the EMG in the gluteus medius and gluteus maximus. Fischer and Houtz examined 11 healthy women between the ages of fifteen and twenty-three years of age. EMG activity was measured in the gluteus maximus, sacrospinalis, medial and lateral hamstrings, and quadriceps femoris muscles. Measurements were taken while the subjects performed a floor-to-waist lift of twenty-five pounds with the knees straight and the trunk and hips flexed versus hips and knees

flexed. The investigators found very little gluteus maximus activation with the knees and tibias forward, but rather strong quadriceps activation. The straight knee and trunk flexed with a twenty-five pound weight demonstrated strong activation of the hamstrings with minimal activation of the gluteus maximus and quadriceps. Along with that, the sacrospinalis muscles showed activation in both lifts. [2,54] The results of Fischer and Houtz differ from Distefano, but this may caused by a greater forward position of the tibia as seen in Fisher and Houtz study, respectively. [2] In addition, Distefano et al chose unilateral limb activities and multiplanar exercises while Fischer and Houtz et al examined bilateral leg activity in the sagittal plane. [2,53,54] Clinical significance is placed upon the correlation between proper biomechanics during functional exercise and strengthening of the gluteus maximus.

Furthermore, side-lying hip abduction and pelvic drops are exercises that have been researched specifically for use in the treatment of iliotibial band syndrome. [2,55] In the study conducted by Distefano et al, side-lying hip abduction showed strong EMG activation, and the single-leg functional activity exhibited higher EMG activation when compared to double-leg closed chain exercise. In continuation, Distefano et al made minor adjustments during functional exercises to recruit the gluteal muscles, such as more vertical tibia, forward trunk activity, and proper trunk position. It is recommended to perform the clam exercise and lunge patterns using a resistance band because without resistance there was less than 60% gluteal activation. [2,53]

A study performed by Barrios et al examined eight non-injured subjects with varus knee alignment between eighteen and thirty-five years of age. The study obtained visual faded feedback, which focused on reducing excessive knee external adduction. Each subject went through eight training sessions, with faded feedback in sessions five through eight. During the sessions, the subjects were verbally instructed to “bring the thighs closer together” and “walk with your knees closer together.” Clinical significance of 20% reduction in knee external adduction moment was noted. [2,55] While the subjects used were non-injured, these results may be beneficial for iliotibial band syndrome patients demonstrating excessive knee varus. Also, real-time visual feedback allows for biomechanical improvement in eight sessions, and this is due to the strong cognitive component provided by visual feedback. [2]

EMG studies, exercise research for iliotibial band syndrome, and case studies have allowed researchers to provide a progression of exercises focused on strengthening the gluteal muscles. Recommendations begin with therapeutic exercises including an iliotibial band stretch, side-lying hip abduction, and pelvic drops with progression to technique-driven closed chain exercises; for instance a single-leg dead lift. Single-leg functional exercises are advised because of their high vigor, and ability to strengthen the gluteal muscles, whereas bilateral closed chain exercises are of lower vigor and are mainly used to develop technique. [2]

Along with that, Fredericson and Wolf expanded iliotibial band syndrome treatment protocol with the inclusion of exercises focused on greater eccentric muscle contractions, triplanar motions, and integrated movement patterns. Such exercises include the modified matrix (figure 7), which can be performed by having the patient stand tall with the left foot to twelve o’clock position and the right foot to the three o’clock position. Next, the patient puts their right

arm in an abducted and externally rotated position, and then the patient rotates their hips toward the left leg and transfers their weight to the left leg, while the patient also reaches with their right arm to a point between the left hip and knee. The patient should be instructed to lower the hips as the spine flexes so that loading is felt in the hips, legs, and lower back. The patient should then return to the starting position, being sure to transfer their weight back to their right leg. [3]

The authors also recommend wall bangers (figure 8), the patient stands 15-30cm from the wall depending on flexibility and strength of the lateral gluteal muscles. The right shoulder is closest to the wall; the patient reaches out to the left, while rotating the hips toward the left foot. The patient should maintain a neutral spine by flexing the knees and dropping the hips. As the patient 'bangs' the right hip against the wall, they should immediately recoil in order to sustain eccentric loading, and return to the stand-tall position. It is important not to allow the patient mover their right hip toward the wall. [3]

In coordination with the following exercises, frontal plane lunges are suggested (figure 9). With a focus on the gluteal muscles, the patient stands with their feet shoulder-width apart, and steps to the nine o'clock position until a stretch is felt then immediately returns to the starting position. Variations can be added to the frontal plane lunge, allowing for development of the supinators and pronators of the loading leg. This is accomplished by performing a contralateral reach to strengthen the supinators and activation of the peroneal muscles, which is the result of supination that occurs due to external rotation of the distal lower extremity during the reach. Medial reach allows for pronation of the subtalar joint and internal rotation reaction of the tibia, femur and hip, which results in strengthening the pronators of the loaded leg. [3]

Figure 7 Figure 8 ptonthenet.com

Figure 9 sportsfitnesshut.blogspot.com

Return-to-Running Phase: As a general rule, resuming participation in sports depends upon being able to properly perform all strengthening exercises without pain. [2,3] Another possible outcome measure is testing the gluteal muscles for proper strength and function. [2,47,49] Previously mentioned, Ober's test can be performed to evaluate hip adduction range of motion, and the modified Thomas test may be used to assess iliotibial band and rectus femoris flexibility. [2,17,41,42] Fredericson and Wolf recommend pain free range of motion in hip adduction before returning to sports. [2] Also, there should be a negative Noble compression test, which is confirmed by no tenderness at the lateral femoral epicondyle when the knee is bent at thirty degrees. [2,3,15]

Surgical Intervention

There are various surgical techniques developed to help decrease tension on the iliotibial band and pressure on the lateral femoral epicondyle. The most common surgical technique removes a triangular section of the iliotibial band that overlies the lateral femoral epicondyle, while the knee is bent at thirty degrees. 3,56 This technique is also known as Z-lengthening.[3,57]

CONCLUSION

Iliotibial Band Syndrome is a common injury among individuals who participate in sports requiring repetitive knee flexion. It is known that improper biomechanics caused by weak muscles such as the gluteus medius will greatly contribute to the development of iliotibial band syndrome as a result of excess adduction. A clinician should be able to easily determine if iliotibial band syndrome is present by performing tests such as Noble, Ober's, modified Thomas, and Trendelenburg.

A considerable amount of research has been conducted in order to understand iliotibial band syndrome. Pubmed generated over 100 articles, discussing how patients develop iliotibial band syndrome, and the best treatment options. There is a lack of research pertaining to soft tissue mobilization techniques, including ART and Graston.

The phases of rehabilitation recommended by Fredericson and Wolf demonstrates how to effectively treat iliotibial band syndrome through a biomechanical approach focusing on integrated movements and triplanar motions to strengthen the lateral hip musculature with inclusion of massage. With an early diagnosis, a complete recovery is expected. However, for

complete resolution of iliotibial band syndrome without remission requires correction of all contributing biomechanical factors.

REFERENCES

1. Bauer, J.A., & Duke, L. M. (2011). Examining Biomechanical and Anthropometrical Factors as Contributors to Iliotibial Band Friction Syndrome. *Sports Science Review, XX* (1-2).
2. Baker, R.L., Souza, R.B., & Fredericson, M. (2011). Iliotibial band Syndrome: Soft Tissue and Biomechanical Factors in Evaluation of Treatment. *American Academy of Physical Medicine and Rehabilitation, 3*, 550-561.
3. Fredericson, M. & Wolf, C. (2005). Iliotibial Band Syndrome in Runners: Innovations in Treatment. *Sports Medicine* (Auckland, N.Z.), *35* (5), 451-459.
4. Kirk, K. L., Kuklo, T., & Klemme, W. (2000). Iliotibial Band Friction Syndrome. *Journal of Orthopedics, 23*, 1209-1214.
5. Adams, W.B. (2004). Treatment Option in Overuse Injuries of the knee: Patellofemoral Syndrome, Iliotibial Band Syndrome, and Degenerative Meniscal Tears. *Current Sports Medicine Report, 3*, 256-260.
6. Hamill, J., Miller, R., Noehren, B., & Davis, I. (2008). A Prospective Study of Iliotibial Band Strain in Runners. *Clinical Biomechanics, 23*, 1018-1025.
7. Kaplan, E.B., (1958). The Iliotibial Tract; Clinical and Morphological Significance. *Journal of Bone and Joint Surgery, 40-A* , 817-832.
8. Falvey, E. C., Clark, R. A., Franklyn-Miller, A., Bryant, A. L., Briggs, C., & McCrory, P. R. (2010). Iliotibial Band Syndrome: An Examination of the Evidence behind a Number of Treatment Options. *Scandinavian Journal of Medicine& Science in Sports, 20*, 580-587.
9. Orchard, J. W., Fricker, P. A, Abud, A. T., & Mason, B. R. (1996). Biomechanics of Iliotibial Band Syndrome in Runners. *American Journal of Sports Medicine, 24*, 375-379.
10. Pedowitz, R. N. (2005). Use of Osteopathic Manipulative Treatment for Iliotibial Band Friction Syndrome. *The Journal of the American Osteopathic Association, 12, 563-567*
11. Rene, J. W. (1975). The Iliotibial Band Friction Syndrome. *Journal of Bone and Joint Surgery, 57,* 1110-1111.
12. Noble, C. (1980). Iliotibial Band Friction Syndrome in Runner. *American Journal of Sports Medicine, 8,* 69-73.
13. Khaund, R. & Flynn, S. H. (2005). Iliotibial Band Syndrome: A Common Source of Knee Pain. *American Academy of Family Physicians,* 1-9.
14. Noble, H., Hajek, M., & Porter M. (1982). Diagnosis and Treatment of Iliotibial Band Tightness in Runners. *Physician & Sportsmedicine, 10* (4), 67-68; 71-72; 74.
15. Noble C., (1980). Iliotibial Band Friction Syndrome in Runners. *American Journal of Sports Medicine, 8*, 232-234.

16. Fairclough, J., Hayashi, K., and Toumi H., et al. (2006). The Functional Anatomy of the Iliotibial Band during Flexion and Extension of the Knee: Implications for understanding Iliotibial Band Syndrome. *Journal of Anatomy, 208,*309-316.
17. Gose, J.C., & Schweizer, P. (1989). Iliotibial Band Tightness. *Journal of Orthopedic Sports Physical Therapy, 10,* 399-407.
18. Page, P., Frank, C., & Lardner R. (2010). Assessment and Treatment of Muscle Imblalance: The Janda Approach. Chicago, IL: Human Kinetics.
19. Hollman, J.H., Ginos, B.E., Kozuchowski, J., Vaughn, A.S., Kraus, D.A., & Youdas, J.W. (2009). Relationship between Knee Valgus, Hip-muscle Strength, and Hip-muscle Recruitment during a Single-limb Step Down. *Journal of Sports Rehabilitation, 18* 104-117.
20. Youdas, J.W, Mraz, S.T., Norstad, B.J., Schinke, J.J., & Hollman, J.H. (2007). Determining Changes in pelvic-on-femoral position during the Trendelenburg Test. *Journal of Sports Rehabilitation*, 16, *326-335*
21. Ferber R., Noehren, B., Hamill, J., & Davis, I.S. (2010). Competitive Female Runners with a History of Iliotibial Band Syndrome Demonstrate Atypical Hip and Knee Kinematics. *Journal of Orthopedic Sports Physical Therapy, 40,* 52-58.
22. Noehren, B., Davis, I., & Hamill, J. (2007). ASB Clinical Biomechanics Award Winner 2006 Prospective Study of the Biomechanical Factors associated with Iliotibial Band Syndrome. *Clinical Biomechanics* (Bristol, Avon), *22* (9), 951-956.
23. Messier, S.P., Edwards, D.G., & Martin, D.F., et al. (1995). Etiology of Iliotibial Band Friction Syndrome in Distance Runners. *Medicine and Science in Sports and Exercise,27* (7), 951-960.
24. Fredericson, M., Cookingham, C.L., bad Chaudhari, A.M., et al. (2000). Hip and Abductor Weakness in Distance Runners with Iliotibial Band Syndrome. *Clinical Journal of Sports Medicine, 10* (3), 169-175.
25. MacMahon, J.M., Chaudhari, A.M., & Adriacchi, T.P. (2000). Biomechanical Injury Predictors for Marathon Runners: Striding towards Iliotibial Band Syndrome Injury Prevention [abstract]. *International Society of Biomechanics* (Hong Kong).
26. Vieira, E.L., Vieira, E.A., da Silva, R.T., Berifein, P.A., Abdalla, R.J., & Cohen, M. (2007). An Anatomic Study of the Iliotibial Tract. *Arthroscopy, 23,* 269-274
27. Fairclough, J., Hayashi, K., & Toumi, H., et al. (2007). Is iliotibial Band Syndrome really a Friction Syndrome? *Journal of Medicine and Science in Sports, 10,* 74-78.
28. Kelly A., & Winston, I. (1994). Iliotibial Band Syndrome in Cyclists. *American Journal of Sports Medicine, 22,* 150.
29. Anderson, G.S. (1991). Iliotibial Band Friction Syndrome. *Australian Journal of Science and Medicine in Sport, 23* (3), 81-83.
30. Lucas, C.A. (1992). Iliotibial Band Friction Syndrome as Exhibited in Athletes. *Journal of Athletic Training, 27* (3), 250.
31. Grady, J.F., O'Connor, K.J., & Bender, J. (1986). Iliotibial Band Syndrome. *Journal of the American Podiatric Medical Association, 76* (10), 558-561.

32. McNicol, K., Taunton, J.E., & Clement, D.B. (1981). Iliotibial Tract Friction Syndrome in Athletes. *Canadian Journal of Applied Sports Sciences, 6* (2), 76-80.
33. Power, C. (2010). The Influence of Abnormal Hip Mechanics on Knee Injury: A Biomechanical Perspective. *Journal of Orthopedic and Sports Physical Therapy,* 40, 42-49.
34. Miller, R.H., Lowry, J.L., Meardon, S.A., & Gillette, J.C. (2007). Lower Extremity Mechanics of Iliotibial Band Syndrome during an Exhaustive Run. *Gait Posture, 26,* 407-413.
35. Barber, F.A., & Sutker, A.N. (1992). Iliotibial Band Syndrome. *Sports Medicine, 14* (2), 144-148
36. Linderburg, G., Pinshaw, R., & Noakes, T.D. (1984). Iliotibial Band Syndrome in Runners. *Physical Sportsmed, 12,* (5), 118-130.
37. Taunton, J.E., Ryan, M.B., Clement, D.B., McKenzie, D.C., Lloyd-Smith, D.R., & Zumbo, B.D. (2002). A Retrospective Case-control Analysis of 2002 Running Injuries. *British Journal of Sports Medicine, 36*, 95-101.
38. Farrell, K.C., Reisinger, K.D., & Tillman, M.D. (2003). Force and Repetition in Cycling: Possible Implications for Iliotibial Band Friction Syndrome. *Knee, 10,* 103-109.
39. Wanich, T., Hodgkins, C., Columbier, J.A., Muraski, E., & Kennedy, J.G. (2007). Cycling Injuries of the Lower Extremity. *Journal of the American Academy of Orthopaedic Surgery, 15*, 748-756.
40. Sutker, A.N., Barber, F.A., Jackson, D.W., & Pagliano, J.W. (1985). Iliotibial Band Syndrome in Distance Runner. *Sports Medicine* (Auckland, N.Z.), 6 (2), 447-451.
41. Clapis, P.A., Davis, S.M., & Davis, R.O. (2008). Reliability of Inclinometer and Goniometric Measurements of Hip Extension Flexibility Using the Modified Thomas Test. *Physio Theory Pract,24* 135-141.
42. Harvey, D. (1998). Assessment of the Flexibility of Elite Athletes using the Modified Thomas Test. *British Journal of Sports Medicine, 32,* 68-70.
43. Fredericson, M., White, J.J., MacMahon, J.M., & Andriacchi, T.P. (2002). Quantitative Analysis of the Relative Effectiveness of Iliotibial Band Stretches. *Arch Phys Med Rehabil, 83*, 589-592.
44. Schwellnus, M.P. (1993). Lower Limb Biomechanics in Runners with the Iliotibial Band Fricition syndrome, abstracted. *Journal of Medicine and Science in Sports and Exercise, 25* (5), S68.
45. Simons, D.G., Travell, J.G., Simons, L.S. (1999). Myofascial Pain and Dysfunction: The Trigger Point Manual. 2nd ed. Baltimore (MD): Williams &WIilkins.
46. Fredericson, M., Guillet, M., DeBenedictis, L. (2000). Quick Solutions for Iliotibial Band Syndrome. *Phys Sportsmed, 28,* 52-68.
47. Kendall, F., McGreary, E., & Provance, P. (1993). Muscles: Testing and Function. 4th ed. Baltimore, Md: Williams & Wilkins.
48. Gray, G. (2001). Total Body Functional Profile. Adrian (MI) : Wyn Marketing.
49. Janda, V. (1983). Muscle Function Testing. London.

50. Lyons, K., Perry, J., Gronlry, J.K., Barnes, I., Antonelli, D. (1983). Timing and Relative Intensity of Hip Extensor and Abdcutor Muscle Action during Level and Stair Ambulation, An EMG Study. *Journal of Physical Therapy, 63,* 1597-1605.
51. Gunter, P., & Schwellnus, M.P. (2004). Local Corticosteroid Injection in Iliotibial Band Friction Syndrome in Runners: A randomized controlled trial. *British Journal of Sports Medicine, 38*, 269-272.
52. Wolf, C. (2002). IDEA. Personal Trainer Magazine. July-August: 20-31.
53. Distefano, I.J., Blackburn J.T., Marshall, S.W., & Padua, D.A. (2009). Gluteal Muscle Activation during Common Therapeutic Exercises. *J Orthop Sports Phys Ther, 39,* 532-540.
54. Fischer, F.J., & Houtz, S.J. (1968). Evaluation of Function of the Gluteus Maximus Muscle. An electromyographic study. *Am J Phys Med, 47,* 182-191.
55. Barrios, I.A., Crossley, K.M., & Davis, I.S. Gait Retraining to Reduce the Knee Adduction Moment through Real-Time Visual Feedback of Dynamic Knee Alignment. *J Biomech, 43,* 2208-2213.
56. Martens, M., Libbrecht, P., and Burssens, A. (1989). Surgical Treatment of Iliotibial Band Friction Syndrome. Am J Sports Med Sept-Oct; 17 (5): 651-654.
57. Richards, D.P., Barber, F.A., & Troop R.L. (2003). Iliotibial Band Z-lengthening. Arthroscopy, (3) . Mar, 19. 326-369.