Muscle performance factors and altered loading mechanics have been linked to a variety of lower extremity musculoskeletal disorders. In this article, biomechanical risk factors associated with iliotibial band syndrome (ITBS) are described, and a strategy for incorporating these factors into the clinical evaluation of and treatment for that disorder is presented. Abnormal movement patterns in runners and cyclists with ITBS are discussed, and the pathophysiological characteristics of this syndrome are considered in light of prior and current studies in anatomy. Differential diagnoses and the use of imaging, medications, and injections in the treatment of ITBS are reviewed. The roles of hip muscle strength, kinematics, and kinetics are detailed, and the assessment and treatment of muscle performance factors are discussed, with emphasis on identifying and treating movement dysfunction. Various stages of rehabilitation, including strengthening progressions to reduce soft-tissue injury, are described in detail. ITBS is an extremely common orthopedic condition that presents with consistent dysfunctional patterns in muscle performance and movement deviation. Through careful assessment of lower quarter function, the clinician can properly identify individuals and initiate treatment.

INTRODUCTION

Iliotibial band syndrome (ITBS) is the leading cause of lateral knee pain in runners and accounts for 15% of overuse injuries in cyclists [1-5]. While balancing the need to promote fitness and the associated risks of repetitive-motion injuries such as ITBS, physicians and other rehabilitation professionals have searched for methods of identifying contributing factors for overuse injuries as well as treatments that restore function and enable patients to maintain their exercise activities.

The first detailed case on ITBS was published by Renne [6] in 1975. The subjects studied were military recruits whose running and training activities had increased rapidly. Hallmarks of ITBS were pain on weight bearing at 30° of knee flexion and the exacerbation of pain after having run more than 2 miles or having hiked more than 10 miles.

Lateral knee pain at the femoral epicondyle is a key finding in patients with ITBS [6-8]. Noble [9] analyzed 100 patients with ITBS and developed the Noble compression test, in which compression over the lateral epicondyle of the femur at 30° of knee flexion elicits pain reproduction. This test is now commonly used to diagnose ITBS. Orchard et al [10] described ITBS in runners as an impingement zone related to the time period just after heel strike as the knee approaches 30° of flexion. The investigators described this as the deceleration phase, which suggests that impingement occurs during eccentric loading of the iliotibial band during the weight-acceptance phase of running.

ANATOMIC CONSIDERATIONS

The iliotibial band is a fascial structure composed of dense connective tissue that assists stance stability and is capable of resisting large varus torques at the knee [7,11,12]. Proximally, the iliotibial band provides an insertion for the tensor fascia lata and gluteus maximus muscles [13]. Based on dissections of 1 orangutan, 3 chimpanzees, 1 gorilla, 1 bear, and other 4-legged animals, Kaplan [13] concluded that, although all quadruped
animals have tensor fascia latae or gluteus maximus muscles, they do not all have an iliotibial band. The investigator then suggests that the iliotibial band is an independent stabilizer of the lateral knee joint, essential for erect posture. The iliotibial band has 2 significant attachments, including the lateral epicondyle and the Gerdy tubercle (Figure 1)[13,14]. The first iliotibial band attachment is into the distal femur at the upper edge of the lateral epicondyle[15]. The histologic makeup is consistent with tendon and has a layer of adipose tissue underneath the iliotibial band attachment area[14,16]. The adipose tissue contains pacinian corpuscles, is highly vascular, and may be the site of the inflammation that causes pain during compression. The second attachment of the iliotibial band is the insertion into the Gerdy tubercle of the tibia and serves as a ligament in structure and function. The Gerdy tubercle attachment is tensed during tibia internal rotation as the knee flexes during the weight-acceptance phase of gait[14,16,17]. Internal tibial rotation explains the occasional connection between toeing in and iliotibial band strain[4,18].

The iliotibial band has many other distal attachments, which include the biceps femoris, vastus lateralis, lateral patellar retinaculum, patella (by way of epicondylar ligament and patellar retinaculum), and patellar tendon[13,14,16]. Collectively, these anterior and lateral attachments form a horseshoe pattern or inverted U shape well positioned for anterolateral support to the knee[15,19,20]. The site of injury is often associated with the insertion at the lateral epicondyle but interrelated with the forces created by the various attachments above and below the lateral epicondyle (Figure 1).

Fairclough et al[14] described a mechanism of compression of the iliotibial band against the lateral epicondyle that occurs at 30° of knee flexion. Their anatomic description included the observation that compression of the adipose tissue at the lateral epicondyle of the femur caused pain and inflammation but that no anterior–posterior movement of the band moving over the epicondyle took place, simply an approximation of the iliotibial band into the lateral epicondyle as the knee internally rotated during flexion from an extended position. The investigators present an anatomical viewpoint that contradicts the commonly held theory of a friction syndrome[14]. Fairclough et al[14] described friction as an unlikely cause of ITBS, because the band inserts deeply and strongly into the femur. The functional anatomy may be relevant because a fat pad and pacinian corpuscle compression mechanism may have different mechanoreceptor implications compared with a friction syndrome, although inflammation remains the primary concern.

**INTRINSIC CONTRIBUTING FACTORS**

**Biomechanics of the Hip, Knee, and Ankle**

Ferber et al[21] attributed iliotibial band strain in female runners to a greater peak hip adduction angle and greater peak knee internal rotation angle compared with those in controls. The investigators used a retrospective design and control group comparison. The theory presented was increased tensile stress at the hip in the frontal plane and internal rotation stress at the knee. Interestingly, in this study, patients with ITBS exhibited femoral external rotation versus internal rotation when compared with control subjects, a factor that increased knee internal rotation.

In 2007, Noehren et al[22] published a prospective study of female runners that analyzed ITBS and biomechanical factors, including hip adduction, knee internal rotation, and rear foot eversion angles, and related hip, knee, and ankle moments. The investigators performed bilateral, 3-dimensional, lower extremity kinematic and kinetic analysis with running. The subjects were followed up for injury findings through 2 years by e-mail communication. Findings for the ITBS group versus the control group included the following: (1) greater peak hip adduction, (2) greater peak knee internal rotation angle, (3) lower tibial internal rotation by 2.2° (not significant), and (4) femoral external rotation. On visual
inspection, the investigators noted that the subjects with ITBS landed in greater hip adduction and knee internal rotation. Noehren et al [22] and Ferber et al [21] support the theory of frontal and transverse plane factors in female runners, specifically, excessive hip adduction and knee internal rotation. Further study is needed to explain why these runners exhibited greater hip adduction, knee internal rotation, and femoral external rotation. In addition, male runners need further assessment in similar research models. Weight-bearing magnetic resonance imaging and dual fluoroscopic imaging may be useful to further assess femoral rotation in male and female runners with and without ITBS, specifically aimed at evaluating the role of transverse plane contributing factors of the hip [23-25].

Hamill et al [12] modeled iliotibial band strain rate with software for interactive musculoskeletal modeling (SIMM 4.0; Motion Analysis Corporation, Santa Rosa, CA). This prospective study of female runners compared iliotibial band strain (calculated as the change in length during running divided by the resting length), strain rate (calculated as the change in strain divided by the change in time), and duration of impingement in 17 patients with ITBS and 17 age-matched controls. The entire stance was measured, with a focus on touch-down and peak knee flexion. Although strain was increased versus that in the control, only strain rate was statistically significant between the groups. The investigators suggested that strain rate is a factor in the development of ITBS.

Taunton et al [5] used a retrospective design to analyze data on 2002 running injuries, including 63 men and 105 women with ITBS. Varus knee alignment was reported in 33%, and valgus alignment was reported in 15%. Leg-length discrepancy, defined as a greater than 0.5-cm difference in anterior superior iliac spine to medial malleolus, reported in 10%. McNicol et al [26] also reported on 52 cases of ITBS in runners, including 34 men and 18 women with ITBS. The investigators reported that 55% had mild-to-severe knee varus, and 8% had mild knee valgus. These studies suggest that clinical management of ITBS may involve training methods to control frontal plane dynamics at the knee, in addition to assessing and treating transverse plane issues.

One way to theoretically visualize the relationship between the hip and knee frontal plane relationships involves the use of ground reaction force diagrams. During normal single-limb stance as described by Powers [27], the ground reaction force vector may pass medial to the knee joint and produce a varus torque at the knee (Figure 2A). However, with excessive hip adduction during a single-limb stance and Trendelenburg sign, the ground reaction force vector may pass more medial, with a larger perpendicular distance to the knee joint (Figure 2B). The result is an increased varus torque at the knee, along with an elongated lateral hip musculature, both of which place increased stress on the iliotibial band [27,28]. The third possible disturbance at the knee is a valgus stress and ground reaction force vector lateral to the knee, combined with an increased hip adduction, a compensated Trendelenburg sign (Figure 2C).

Abnormal mechanics at the foot and the tibia may play a role in the development of ITBS given the anatomic connection of the iliotibial band to the tibia and the interrelationship of the foot and the tibia. Noehren et al [22] analyzed biomechanical factors in the hip, knee, and rear foot in female runners who go on to develop ITBS, and, although hip adduction and knee internal rotation were the primary findings in this cohort, these investigators were able to identify a subset of 4 participants who exhibited excessive calcaneal...
Eversion and tibial internal rotation. In contrast, Messier et al [29] performed a cross-sectional lower extremity kinematic study on male and female patients with ITBS and reported no statistically significant differences in rear foot eversion when compared with a control group.

Miller et al [30] analyzed 16 runners, 8 with history of ITBS and 8 age-matched controls, in an exhaustive run. At the end of the run, the patients in the ITBS cases exhibited greater maximum foot inversion (3.3° ITBS and −9.5° control), maximum knee flexion at heel strike (43.8° ITBS and 36.5° control), and maximum knee internal rotation velocity (16.4%/s ITBS and 10.3%/s control). Further research is needed to better understand the possible connection between the foot mechanics and increased knee internal rotation velocity.

Leg-length discrepancies have been reported as a factor in developing ITBS. McNicol et al [26] studied 52 cases of ITBS in runners and reported that 13% had leg-length discrepancies, and, in all cases, that the side of injury corresponded with the longer leg. However, Messier et al [29] evaluated a variety of intrinsic and extrinsic factors in 56 patients with ITBS and 70 controls, reporting leg-length discrepancies consistent between the control group and the injured group. Taken together in a clinical perspective, ITBS and foot and ankle factors suggest a possible subset of cases in runners who have abnormal foot and ankle biomechanics, including excessive calcaneal eversion and tibial internal rotation along with leg-length discrepancy.

**Muscle Performance**

Messier et al [29] reported generalized strength and endurance considerations as a possible etiologic factor in male and female participants with ITBS. Fredericson et al [3] reported significant hip abductor strength deficits in patients with ITBS compared with noninjured control runners, and good success in these injured patients after a 6-week strengthening program focused on strengthening the gluteus medius muscle. Miller et al [30] reported that, on average, patients in the ITBS cases were tighter in the iliotibial band than control runners when the Ober test was used. The investigators also reported an increased maximum knee internal rotation velocity in patients in the ITBS cases near exhaustion, which suggests fatigue-related factors. In a separate study that evaluated runners during an exhaustive run, Miller et al [31] suggested that runners with a history of ITBS use abnormal segmental coordination patterns. The scope of muscle performance factors in ITBS includes strength, endurance, flexibility, and segmental coordination (Figure 3).

The Janda approach to muscle imbalance provides a theoretical model that assists in the analysis of muscle strength and flexibility as it relates to excessive hip adduction and knee varus or valgus. The tensor fascia lata is classified by Janda as a postural muscle with the tendency to become shortened and strong. The clinical finding is increased hip flexion in stance, along with a tendency for increased hip internal rotation [3,32-37]. In contrast, the gluteus maximus and gluteus medius are phasic muscles with the tendency to become lengthened and weak [36,37]. Subsequently, the taut and relatively stronger tensor fascia lata may dominate the weaker gluteus medius posterior and gluteus maximus, and may result in a postural pattern, including a Trendelenburg sign (Figure 2B) or compensated Trendelenburg sign (Figure 2C) [27,38]. These compensations during walking or running may result in poor control of the hip and femur during stance and may lead to excessive hip adduction and knee varus or valgus. The Janda-based analysis of muscle imbalance provides a theoretical construct to understand and treat some of the factors related to ITBS, specifically, strengthening of the gluteus medius and gluteus maximus muscles to better control hip adduction and knee varus and valgus.

**EXTRINSIC CONTRIBUTING FACTORS**

Extrinsic factors are related to training methods as well as running shoes or cycle fit, and have been researched and reported in connection with ITBS [2,4,10,29]. Key elements in such research include repetitions at about 30° of knee flexion (the impingement zone) in a closed-chain and weight-bearing position. Farrell et al [2] analyzed cycling kinematic and kinetic data to reported values for running, with a focus on iliotibial band impingement at the knee.
noninjured cyclists were analyzed with motion analysis and synchronized foot-pedal forces. Findings included the following: (1) lower pedal reaction force at 17%-19% versus ground reaction force in runners, and (2) shorter impingement zone contact time, calculated at 38 ms in cyclists versus 75 ms in runners. However, the investigators discussed the issue of repetitive stress in a typical workout, commenting that cycling results in more repetitions (ie, 6600 repetitions during a 1.25-hour ride versus 4800 repetitions during a 10-km run). Interestingly, Farrell et al [2] described a theoretical mechanism of stress to the iliotibial band in cyclists in which the shorter leg, when fixed to the pedal, is over-stretched laterally and functions in less knee flexion, thereby increasing the time spend in the impingement zone. Whether running or cycling, the factors of impingement time and intensity of loading are important.

Training factors, including rapid increases in mileage and hill training, can lead to iliotibial band injury [2,29]. Orchard et al [10] suggested that increased impingement zone impact time during both downhill and slow running leads to ITBS and sprinting may result in relatively less impact time because of greater knee flexion beyond the impingement zone. This particular theory was not supported by Miller et al [30], who found, during an exhaustive run, increased knee flexion at heel strike in runners with a history of ITBS. Our review did not find experimental studies that evaluated the effect of sprinting on iliotibial band strain or impingement, although the topic seems relevant for future research. Messier et al [29] reported that less experienced runners with rapid changes in mileage were at risk for ITBS, but hypothesized that intrinsic factors, including strength deficits, were necessary for extrinsic factors to cause symptoms. The investigators also reported increased cross-training habits (ie, swimming and cycling) in runners with ITBS versus the control group.

**CLINICAL EXAMINATION**

Sutker et al [39] evaluated 1030 runners with lower extremity complaints and diagnosed 48 cases of ITBS. Subjectively, the patients described lateral knee pain associated with repetitive loading in a weight-bearing position (ie, running and stairs). Functionally, the runners were able to perform activities such as a hop and squat without pain. This contrasts with the cases presented by Renne [6], in which military recruits in daily training exhibited a limp and straight leg gait pattern. Renne [6] also noted that the symptoms were aggravated by running more than 2 miles and hiking more than 10 miles. Sutker et al [39] confirmed the diagnosis of ITBS by the history and tenderness localized at the lateral epicondyle of the femur or less commonly at the Gerdy tubercle. Concurrently, the patients did not have symptoms at the lateral joint line or popliteal tendon, and did not have signs of intra-articular disorders.

The subjective examination includes the clinical application of previous information on factors associated with ITBS. Taunton et al [5] reported on 168 cases of ITBS with a distribution 38% men, 62% women, average weekly hours of running 4.9, training years 7.3, body mass index of 23.7 for men and 21.2 for women, and age 31.1 years. Only age younger than 34 years in men was a significant factor among these variables. ITBS was associated with pain after a run that restricted the ability to run. McNicol et al [26] reported 52 cases of ITBs; 42% were found to be related to training errors, such as rapid commencement (2 cases), sudden hill exposure (1 case), single severe session (12 cases), rapid increase volume of training (7 cases), and footwear and surface issues (4 cases). Similarly, Messier et al [29] studied 48 cases of ITBS; compared with 70 controls and reported ITBS cases, the patients had increased training mileage and less experience. In summary, the subjective examination in cases of ITBS has the defining characteristics of lateral knee pain with repetitive knee activity usually in a weight-bearing position and associated overtraining issues.

Objectively, the Noble compression test may be used to provoke symptoms by compressing the iliotibial band at the lateral epicondyle with 30° knee flexion [9]. The patient is positioned with the knee at 90° flexion, and compression is applied just proximal to the lateral epicondyle as the knee is extended toward full extension. The 30° flexion is the impingement zone specific to the iliotibial band and lateral femoral epicondyle as described in cadaver studies by both Orchard et al [10] and Fairclough et al [14]. Differentiating related structures uses this impingement zone concept as well as lack of other objective test findings for injury to the lateral meniscus, lateral retinaculum, popliteus and biceps femoris tendons, patellofemoral joint, and lateral collateral ligament. Although not frequently used for diagnosis, Ekman et al [40] used magnetic resonance imaging to evaluate 7 patients with ITBS and 10 age- and gender-matched controls. The investigators reported thickening of the iliotibial band over the lateral femoral condyle (5.49 mm ITBS and 2.52 mm control; P < .05) and fluid deep to the iliotibial band at the lateral epicondyle in 5 of 7 cases.

**Clinical Assessment of Flexibility**

Flexibility of the lateral hip musculature has routinely been tested as a factor in ITBS [33]. The rationale in testing and treating is related to muscle performance factors (Figure 3) and biomechanical factors, given the issue of iliotibial band compression at the lateral epicondyle of the femur. Messier et al [29] analyzed stretching habits in 56 runners with ITBS and 70 controls and found that both groups stretched, but differences were not established. Fredertson et al [41] analyzed the effectiveness of 3 iliotibial band stretches, in 5 male elite distance runners, and found significant changes in the iliotibial band length in all 3 types of stretching. The investigators proposed benefits to stretching such as reducing iliotibial band tension by hip abductor muscle inhibition and...
improvement in fascial adhesions and myofascial trigger points.

The Ober test is commonly performed to assess iliotibial band length. Gose and Schweizer [42] describe the Ober test as follows: (1) position the patient on side, lying with the tested leg up; (2) with the knee flexed to 90° and the pelvis stabilized, position the hip in a flexed and abducted posture; (3) extend the hip to achieve adequate extension so that the iliotibial band is over or behind the greater trochanter; and (4) allow the thigh to fall into adduction (Figure 4). The iliotibial band restriction is designated as follows: (a) minimal (adducted past the horizontal but not fully to the table), (b) moderate (adducted to the horizontal), and (c) maximal (patient is unable to adduct to the horizontal).

Because the Ober test requires adequate hip extension (approximately to a neutral hip with knee flexed 90°), the use of the modified Thomas test is also recommended. Clapis et al [43] evaluated 42 noninjured subjects in the modified Thomas test by using an inclinometer and goniometer to measure joint ranges. The subjects sat close to the edge of the table, supported the left thigh to the chest, and rolled back to the supine position. The right leg was positioned to hang off the table. To standardize the measurements, the lumbar lordosis was flattened and palpated in that position during the test. The tested hip was placed in neutral hip abduction–adduction. A goniometer was aligned proximally with the midline of pelvis and distally with the midline of the femur. Interclass correlation (ICC) measurements by goniometer were 0.92 and by inclinometer were 0.89. Harvey [44] analyzed the modified Thomas test in 117 elite athletes in tennis, running, rowing, and basketball. ICCs were 0.91-0.94, and findings were as follows: (1) psoas averaged −11.9° (below the horizontal), (2) quadriceps was 52.5°, and (3) tensor fascia lata–iliotibial band averaged 15.6° abduction.

**Clinical Assessment of Strength**

The functionally weak gluteus medius and gluteus maximus reduces eccentric control of the hip and femur in stance [33,34]. To detect hip muscle imbalance between the tensor fascia lata and the gluteus medius and maximus, the clinician can perform surface electromyography (EMG) to observe for muscle substitution: (1) tensor fascia lata may substitute for the posterior fibers of the gluteus medius, and (2) hamstring may substitute for the gluteus maximus as described by Kendall et al [38]. Functional tests offer insight into muscle substitutions on a regional basis, such as trunk and lower-extremity strength, including signs of excessive femur internal rotation, ipsilateral hip adduction, and contralateral hip drop during a step-down test or Trendelenburg test (Figures 5 and 6) [37,45,46]. The utility of the standing functional tests is debated based on minimal detectable change and whether or not weakness exists in the hip musculature (ie, gluteal muscles) or core stabilizers (ie, internal obliques, transverse abdominus, multifidus) [37,46]. However, the functional tests may identify muscle performance factors that a patient can see firsthand, a powerful motivator in treatment compliance. The gluteus maximus muscle strength should also be tested, given its role of hip stabilizer in the frontal plane [47] and ability to influence femur rotation (ie, concentric femur external rotation and eccentric femur internal rotation) [36,38,47]. Testing the gluteus maximus can be performed with the patient in the prone position with the knee flexed to 90° and the hip in neutral rotation by using a manual muscle test or hand-held dynamometer against the
lower portion of the posterior femur [36,38,48]. The patient should be able to fully resist without a break and should have symmetrical strength side to side. The deep external rotator muscles are important stabilizers of the hip, including the obturator internus and externus, gemellus superior and inferior, quadratus femoris, and piriformis [49]. The muscle test position described by Janda [36] is supine, test leg off the table and nontest leg flexed at the hip and the knee, with the foot on the table, fixate below the distal femur, and resistance applied above the medial malleolus as the patient moves through full range.

**Treatment**

Fredericson and Wolf [33] developed a useful format for stages of treatment (Table 1): acute, subacute, and recovery strengthening. Treatment of ITBS is driven by the pathophysiology of inflammation and the biomechanics of iliotibial band strain [32,33]. The path to recovery involves correction of contributing factors such as weakness of the gluteus medius and excessive hip adduction and knee internal rotation, leg-length discrepancies, and excessive knee varus or valgus strain.

Given the finding of soft-tissue thickening and fluid under the iliotibial band at the lateral epicondyle [8,40], the early use of anti-inflammatory medications, soft-tissue mobilization, and stretching are advised [7,8,33,39,50]. Ellis et al [1] performed a systematic review of conservative treatments for ITBS. By using the Physiotherapy Evidence Database criteria, corticosteroid injection and nonsteroidal anti-inflammatory medications were moderately supported within the first 14 days and anti-inflammatory–analgesic after 14 days. If there is significant swelling or tenderness at the lateral epicondyle resistant to oral anti-inflammatory medication and physical therapy modalities, then a corticosteroid injection at the lateral epicondyle of the femur should be considered early in the treatment course [51].

Patient education is critical to success. Extrinsic factors have been described, including excessive weekly mileage, overtraining, hill training, and other activities that place the iliotibial band in the impingement zone, for example, swimming [5,26,29]. Sutker et al [39] reported on 48 cases of ITBS and found a trend in running 20-40 miles per week for more than 1 year. McNicol et al [26] reported on 52 cases of ITBS in athletes and found that 26 cases involved training-related issues.

Exercise approaches for ITBS have thus far supported strengthening of the gluteus medius (ie, side-lying hip abduction and hip hiking) [3,52]. Approaches to hip strengthening are rapidly increasing, especially targeted to the gluteus medius and maximus [53,54]. Some experts (ie, Fredericson, Geraci) have recommended innovative closed chain approaches to treating ITBS, such as triplanar lunge and squat exercises [33,34].

EMG activation studies of the gluteal muscles provide direction to therapeutic exercise programs. Distefano et al [55] analyzed mean EMG as a percentage of maximal volun-

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**Table 1. Phases of rehabilitation recommended by Fredericson and Wolf [33]**

**Acute Phase**

<table>
<thead>
<tr>
<th>Goal: Reduce inflammation of the iliotibial band at the lateral femoral epicondyle (Figure 1)</th>
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<tbody>
<tr>
<td>1. Control extrinsic factors, such as rest from running and cycling</td>
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<tr>
<td>2. In severe cases patients should avoid any activities with repetitive knee flexion-extension and swimming using only their arms and a pool buoy</td>
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<tr>
<td>3. The use of concurrent therapies is advised (ie, ice, phonophoresis, or iontophoresis) (1.50)</td>
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<td>4. Oral, nonsteroidal anti-inflammatory medication is recommended</td>
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<tr>
<td>5. Corticosteroid injection, if no response to the above methods</td>
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<td>6. Up to 2 pain-free weeks before return to running or cycling in a graded progression</td>
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**Subacute Phase**

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<tr>
<th>Goal: Achieve flexibility in the iliotibial band as a foundation to strength training without pain</th>
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<tr>
<td>1. Iliotibial band stretching (Figure 7)</td>
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<tr>
<td>2. Soft tissue mobilization to reduce myofascial adhesions</td>
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**Recovery Strengthening Phase**

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<tr>
<th>Goal: Strengthen the gluteus medius muscle including multiplanar closed chain exercises</th>
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<tr>
<td>1. Exercises should be pain free</td>
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<td>2. Repetitions and sets of exercises are 8-15 repetitions and 2-3 sets</td>
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<tr>
<td>3. Recommend the exercises of sidelying hip abduction, single leg activities, pelvic drops, and multiplanar lunges</td>
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tary isometric contraction in 21 healthy subjects during a variety of open and closed chain exercises for the gluteus medius and gluteus maximus. The only resistance was segmental body weight, gravity, and resistance bands. The investigators were careful to use positions that promoted a gluteal recruitment pattern, such as a vertical tibia with lunging and forward trunk by hip flexion with squat activity. The list of compared exercises included side-lying hip abduction, clam shell, lateral band walks, single-limb squat, single-limb dead lift, multiplanar lunges, and multiplanar hops. The ICC3,1 were 0.85-0.98 for gluteus maximus and 0.93-0.98 gluteus medius except for multiplanar hops. The investigators proposed that 60% or greater normalized EMG as a percentage of maximal voluntary isometric contraction was the requirement for a strengthening exercise [55,56]. The gluteus medius averaged 61% lateral band walk, 64% single-limb squat, and 81% side-lying hip abduction. The gluteus maximus averaged 59% in single-limb dead lift and single-limb squat. The side-lying clam shell did not use a resistance band and achieved 38%-40% activation in the gluteus medius. This study supported the use of functional-based exercises and open chain resistance exercises to strengthen the gluteal muscles from the viewpoint of EMG patterns.

The positioning of the trunk and degree of knee flexion may change the EMG in the gluteus medius and maximus. Fischer and Houtz [57] analyzed a floor-to-waist lift of 25 lb (0.91 kg) with the knees straight and the trunk and hips flexed versus hips and knees flexed (ie, forward tibias) in 11 healthy women, aged 15-23 years. EMG activity was measured in the gluteus maximus, sacrospinalis, medial and lateral hamstrings, and quadriceps femoris muscles. The investigators demonstrated that the 25-lb (0.91-kg) lift with knees flexed and tibias forward generated a strong quadriceps EMG and minimal gluteus maximus EMG. The straight knee and trunk flexed 25-lb (0.91-kg) lift produced minimal quadriceps and gluteus maximus EMG but strong hamstring EMG. The sacrospinalis muscle was active in both lifts. When compared with the EMG and exercise activities in the Distefano study [55], the differences may be related to the position of the tibia, because Fischer and Houtz [57] allowed a much greater forward position of the tibia. In addition, Fischer and Houtz [57] used a bilateral leg activity in the sagittal plane, whereas Distefano et al [55] chose more unilateral limb activities and multiplanar tasks. The clinical significance is that the biomechanical details in functional exercise are critical to strengthening the gluteal muscles (ie, single leg, multiplanar, vertical tibia).

Noehren et al [58] used real-time visual biofeedback to successfully train 10 female subjects with anterior knee pain and a diagnosis of patellofemoral pain syndrome. Inclusion also required excessive hip adduction on motion analysis. The hip adduction angle was displayed onto a monitor placed in front of the treadmill. Instructions were to contract the gluteal muscles and run with the knees pointed straight ahead, and to maintain a level pelvis. The sessions progressed from 15-30 minutes over 8 sessions, and the visual feedback was faded in sessions 5-8. The participants were not allowed to run outside this training. The program involved faded feedback over 8 treatment sessions (4 times per week for 2 weeks). The result was a 23% decrease in ipsilateral hip adduction during running that was maintained at 1-month follow-up. Although patellofemoral pain cases with other biomechanical issues such as increased hip internal rotation, the relevance to ITBS is the possible use of faded feedback in running to control excessive hip adduction. Similarly, Barrios

**Figure 7.** Iliotibial band stretch in standing (41).

**Figure 8.** Resisted clam shell is a beginning-level exercise for gluteal muscle recruitment.
et al [59] studied visual faded feedback to reduce excessive knee external adduction moment during treadmill walking in 8 noninjured participants with varus knee alignment, aged 18-35 years. The verbal cues to the participants were “bring the thighs closer” and “walk with your knees closer together” while maintaining a normal foot progression angle. The training was 8 sessions with faded feedback in sessions 5 through 8. Statistical significance was reported before to after training for knee external adduction moment, on average 20% reduction ($P = .027$). Although performed on noninjured participants with varus alignment, this particular approach may assist patients in ITBS cases with excessive knee varus. In practice, real-time visual feedback has a strong cognitive component that allows biomechanical improvements in 8 sessions.

The exercises that have been researched specific to ITBS have included side-lying hip abduction and pelvic drops at 3 sets and 30 repetitions and 6 weeks of treatment [3]. The side-lying hip abduction exhibited strong EMG activation in the study by Distefano et al [55], and single leg functional activity demonstrated higher EMG activation versus double-leg closed chain exercise. Furthermore, as stated previously,
the study by Distefano et al [55] used several other useful modifications in functional exercises that seemed to facilitate gluteal recruitment: (1) more vertical tibia, (2) forward trunk lean, (3) resistance band with side walks, (4) multiplanar activity, and (5) good control of trunk position. The clam shell exercise without the resistance band, and the lunge patterns without use of added weight, demonstrated gluteal muscle EMG less than 60%, therefore, we recommend use of resistance with these exercises.

Based on these EMG studies [55,57], research on exercise and ITBS [3,52], and recent case studies focused on strengthening the gluteal muscles [53,54], our recommended progressions of therapeutic exercise include one iliotibial band stretch, side-lying hip abduction and pelvic drops, and a progression of technique-driven closed chain exercises, as illustrated in Figures 7-17 (ie, vertical tibia and trunk flexion from the hips). The bilateral closed chain exercises are relatively low vigor and were used early in the recovery to promote technique in squats, whereas the single-leg activities are of higher vigor and intended for strengthening the gluteal muscles.

RESUMING PARTICIPATION IN SPORTS

Participation in sports is dependent upon being able to perform exercises in proper form without pain [11,33]. Other outcome measures include strength testing the gluteus maximus control.

Figure 13. Resisted squat is an intermediate exercise that uses hip abduction and vertical tibial alignment to facilitate gluteus maximus control.

Figure 14. Resisted staggered squat is an intermediate exercise to facilitate gluteal muscles and an alternative functional stance.

Figure 15. Resisted squat with a single-leg emphasis is a more vigorous exercise to facilitate single-leg control with the gluteal muscles, facilitated by hip abduction and external rotation.

Figure 16. Posterior lunge slide is a more vigorous leg exercise for functional hip control.
medius and gluteus maximus with a normal result [36,38]. The flexibility of the iliotibial band and rectus femoris can be assessed with a modified Thomas test as previously described [43,44]. The Ober test can be used to assess hip adduction range of motion as previously described [42]. Our recommendation on flexibility testing and return to sports is pain-free range of motion in hip adduction. There should be a negative Noble compression test, with the absence of tenderness at the lateral epicondyle of the femur at 30° knee flexion [9].

Runners and cyclists should train on level ground every other day [33,60]. The distance and frequency of training should be increased incrementally and monitored for the recurrence of symptoms. Cross training is not recommended if the activities involve repeated knee flexion through the impingement zone, such as combining hill running, track running, swimming, and cycling [10,29]. Orthotic recommendations are worth considering in a runner if the patient has excessive calcaneal eversion and tibial internal rotation during functional tasks and increased leg length greater than 0.5 cm [5,26].

The cyclist is advised to check bicycle fit for factors related to the 30° impingement zone and the toe-in position [2]. Wanich et al [60] recommended lowering the seat beyond the typical height to decrease knee extension and related iliotibial band stress, and more upright handlebars and a forward seat to reduce passive stretch to the gluteus maximus and iliotibial band. The investigators also recommended addressing cleat position and use of orthotics, such as wedges, to control excessive tibial internal rotation and foot hyperpronation. Flexibility was emphasized for the gluteus maximus and iliotibial band and, more generally for the hamstrings and gastrosoleus muscles. Holmes et al [4] treated 61 cyclists with ITBS by using the following training modifications: (1) flat terrains, (2) controlled mileage (ie, 1/2 mile for 2 weeks), (3) easy pedalling at 80 revolutions per minute, and (4) pain free. The investigators also modified the bicycles based on misalignments identified during the evaluation of bicycle fit, for example, adjusting cleat or pedal positions to reflect the cyclist’s normal off-bicycle alignment and lowering the seat to achieve 30°-32° of knee flexion at the bottom center of the pedaling stroke. Floating pedal systems were selected when fixed pedals did not allow for correction of anatomic variants, and 2-mm spacers were used to correct a short leg.

CONCLUSION

Several intrinsic and extrinsic contributing factors for ITBS have been described. Reduced hip muscle performance and abnormal hip and knee mechanics during functional tasks may be primary contributors to ITBS. Addressing these underlying factors is critical to the efficient management of patients with this condition. Although controversy exists regarding the mechanism of ITBS, controlling inflammation and symptoms during early phases and progressive strengthening in later phases is recommended. ITBS remains a common and challenging dysfunction in many athletes; but, through early diagnosis and proper biomechanical movement analysis, appropriate interventions can be implemented to decrease pain and to improve function.

REFERENCES
