

Anatomical Factors Associated with Overuse Sports Injuries

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Summary

Overuse injuries develop when repetitive stress to bone and musculo-tendinous structures damages tissue at a greater rate than that at which the body can repair itself. A combination of extrinsic factors, such as training errors and environmental factors, and intrinsic or anatomical factors, such as bony alignment of the extremities, flexibility deficits and ligamentous laxity, predispose athletes to develop overuse injuries. Malalignment of the lower extremity, including excess femoral anteversion, increased Q angle, lateral tibial torsion, tibia vara, genu varum or valgum, subtalar varus and excessive pronation are frequently cited as predisposing to knee extensor mechanism overuse injuries. These and other forms of malalignment have also been implicated in iliotibial band syndrome, medial tibial stress syndrome, lower extremity stress fractures and plantar fasciitis. Muscle inflexibility aggravates and predisposes to the development of a variety of overuse injuries, especially those occurring in children and adolescents, including the traction apophysitis. Flexibility deficits may be improved by an appropriate stretching programme. Unfortunately, lower extremity malalignment is less amenable to intervention. Orthotics are often prescribed to improve lower extremity alignment. However, studies have not shown that orthotics have any effect on knee alignment and, while they can alter subtalar joint alignment, the clinical

benefit of this remains unclear. Awareness of anatomical factors that may predispose to overuse injuries allows the clinician to develop individual prehabilitation programmes designed to decrease the risk of overuse injury. In addition, the clinician can advise the athlete on the importance of avoiding extrinsic factors that may also predispose to overuse injury.

Approximately half of all sports injuries in both adults and children may be attributed to overuse or repetitive microtrauma rather than to a single traumatic event. The aetiology of these injuries is multifactorial with both extrinsic factors and intrinsic factors contributing. Extrinsic factors include inadequate footwear, the training surface, faulty biomechanics and training errors. Intrinsic factors related to the anatomical alignment of the extremity and joint range of motion are the focus of this review. The reader is referred to other sources for discussion of extrinsic factors and their role in the development of overuse injuries.

The influence of anatomical factors on overuse injuries is not yet completely understood and existing studies often conflict with one another. It is not possible to perform prospective, randomised studies to assess the relationship between anatomical factors and injury. Existing studies are correlative and the finding of an association between a specific anatomical factor and an overuse injury does not prove cause and effect. In addition, the examination techniques used to assess anatomical factors in these correlation studies have not been evaluated systematically for reliability and repeatability.

Anatomical factors appear to play a larger role in the development of lower extremity than upper extremity overuse injuries. The publication by James et al.^[1] on runners' injuries was instrumental in focusing the sports medicine community on the role of malalignment in overuse injuries. Knee extensor mechanism disorders such as patellofemoral stress syndrome are the overuse injuries associated with the greatest number of anatomical factors. Unfortunately, when all factors contributing to overuse injuries are considered, anatomical factors are the least amenable to correction. The epidemiology, treatment and prevention of specific overuse

injuries will be discussed only as they pertain to anatomical factors. Other contributing factors are equally important, and the reader is referred to sports medicine texts for their discussion.

1. Overuse Injuries

Overuse injuries develop when cumulative repetitive force is greater than that which a specific tissue is able to withstand. The tissue is continually injured on the microscopic level and cannot repair itself as rapidly as the damage is being done. The level of force which a given tissue can withstand may be increased by gradually increasing the training load (allowing the tissue time to adapt), improving flexibility and strength, improving sport related biomechanics and, where possible, correcting anatomical malalignment.

Overuse injuries affect several types of tissue, but the musculotendinous unit is most commonly involved in adults.^[2] Patellar tendinitis, iliotibial band syndrome, Achilles tendinitis, supraspinatus and biceps tendinitis, and lateral epicondylitis are all overuse injuries of the muscle tendon unit. In adolescent athletes, the apophysis is more vulnerable to overuse injury.^[3] Traction apophysitis occurs at the medial epicondyle of the elbow (Little League elbow), the tibial tubercle (Osgood Schlatter's disease), the inferior pole of the patella (Sinding-Larsen-Johansson syndrome), the calcaneus (Sever's disease), the ischial tuberosity (origin of semimembranosus, semitendinosus and biceps femoris long head muscles) and other sites. The pathophysiology of patellofemoral stress syndrome is unclear, as athletes may be symptomatic without pathological changes in either the patella or its articular cartilage. The most severe overuse injuries are stress fractures most commonly occurring in the tibia and tarsal bones.

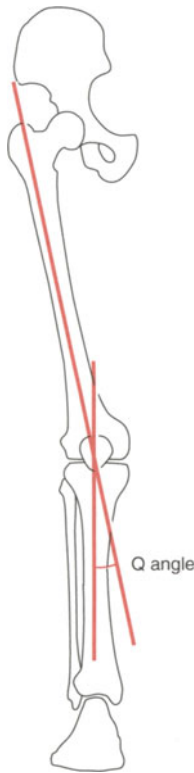


Fig. 1. The static Q angle is determined by measuring the acute angle produced by the intersection of 2 lines. The first line is drawn through the anterior superior iliac spine and the midpoint of the patella. The second line is drawn through the midpoint of the patella and the tibial tubercle. Clinically, a goniometer may be used to measure this angle.

2. Anatomical Factors

Anatomical factors related to overuse injuries may be divided into 2 categories: bony factors and soft tissue factors. Bony factors relate to the alignment of the extremity and the geometrical configuration of components of the skeletal system, such as the patella or the acromion. These factors can only be altered surgically, and this is rarely recommended. Rather, clinicians should recognise bony factors predisposing the athlete to overuse injury so that other controllable risk factors, such as training errors and environmental factors, may be avoided. Soft tissue factors affect joint range of motion; the

structures involved are muscle, tendon, and ligament. Flexibility deficits predispose to many overuse injuries, and ligamentous laxity may also predispose to certain types of injury. Flexibility deficits may be addressed by an aggressive stretching programme. It may be possible to counter the deleterious effects of excessive ligamentous laxity by strengthening muscles around the lax joint.

Bony anatomical factors associated with overuse injuries in the lower extremity affect the alignment of the extremity. These include pelvic width, excessive femoral anteversion or retroversion, the static and dynamic quadriceps or Q angle (fig. 1), genu varum and valgum, tibial torsion, subtalar joint varus and valgus, and pronation and supination of the foot. Other bony factors related to overuse injuries include the shape of the femoral intercondylar notch, the size and shape of the patella and the shape and slope of the acromion. The presence of patella alta, pes planus or cavus, Morton's toe or a leg length discrepancy also predispose to certain overuse injuries. Table I shows the specific overuse injuries that have been associated with each one of these factors.

Flexibility deficits are especially prominent in adolescents with overuse injuries. During the adolescent growth spurt, the growth of long bones precedes and serves as a stimulus to muscle growth and elongation. Muscles which cross 2 joints, such as the rectus femoris and gastrocnemius, may become especially tight during this time period. Tight muscles pull on apophyses and press against or snap across bony prominences. Pain on the opposite side of the joint is often caused by muscle inflexibility.^[4] Flexibility deficits predisposing to overuse injuries have been identified in the ilio-
psoas, iliotibial band, rectus femoris, hamstrings, gastrocnemius and shoulder external rotators (infraspinatus, teres minor). Table II lists flexibility deficits associated with specific overuse injuries.

Physical examination of the athlete should include assessment of both anatomical alignment and flexibility. Key aspects of alignment include an estimate of femoral anteversion made by comparing medial and lateral hip rotation with the hip extended,

Table I. Bony anatomical factors associated with overuse injuries

Factor	PFSS	JK	MTSS	ITB	Plantar fasciitis	Stress fracture
Femoral anteversion/torsion	X					
Pelvic width	X					
Q angle	X	X				
Femoral intercondylar notch shape	X					
Patella shape	X					
Patella alta	X	X				
Lateral tibial torsion	X		X			X
Tibia vara	X			X		X
Genu varum	X			X		X
Genu valgus	X		X			
Subtalar varus	X			X		X
Subtalar valgus	X		X	X	X	X
Pronation	X		X	X	X	X
Morton's toe						X
Leg length discrepancy		X	X	X	X	X
Foot cavus					X	X

Abbreviations: ITB = iliotibial band syndrome; JK = jumper's knee; MTSS = medial tibial stress syndrome; PFSS = patellofemoral stress syndrome.

measurement of static Q angle (fig. 1), observation of patellar position, an estimate of tibial torsion made by measuring the thigh foot angle (fig. 2), observation of knee and subtalar joint valgus or varus (fig. 3) and observation of forefoot pronation or supination during ambulation. The terms pronation and subtalar joint valgus or heel valgus are often used interchangeably and for practical purposes are interchangeable. Technically, the term pronation describes a combination of subtalar valgus, forefoot adduction and ankle dorsiflexion. Leg length discrepancy may be detected by pelvic levelling or by measurement of true leg length

(distance from anterior superior iliac spine to medial malleolus). A quick flexibility screen includes the Thomas test to assess iliopsoas tightness [fig. 4 (top)], the Ober test for iliotibial band tightness [fig. 4 (middle)], the Ely test for rectus femoris flexibility [fig. 4 (bottom)], measurement of popliteal angle for hamstring flexibility (fig. 5), and measurement of ankle dorsiflexion with the knee both flexed and extended (soleus and gastrocnemius flexibility respectively). Measurement of internal and external rotation of the abducted shoulder provides information on rotator cuff flexibility imbalance.

Table II. Flexibility deficits associated with overuse injuries

Muscle	Lesser trochlear apophysitis	PFSS	JK	OS	MTSS	ITB	Plantar fasciitis	Sever's disease	Accessory navicular	Anterior impingement
Iliopsoas	X									
ITB						X				
Rectus femoris		X	X	X						
Hamstrings		X	X	X						
Gastrocsoleus		X			X		X	X	X	
Tibialis posterior										
Shoulder external rotators										X

Abbreviations: ITB = iliotibial band syndrome; JK = jumper's knee; MTSS = medial tibial stress syndrome; OS = Osgood Schlatter's disease; PFSS = patellofemoral stress syndrome.

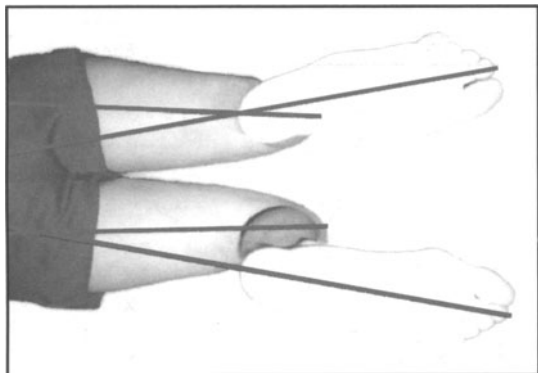


Fig. 2. The thigh foot angle is measured with the athlete prone, the knees flexed 90°, and the feet relaxed with the subtalar joint in a neutral position. The acute angle formed by the intersection of a line from the midpoint of the heel to the second toe and a line parallel to the midline of the thigh is the thigh foot angle. This angle approximates tibial torsion.

Flexibility and anatomical alignment are measured statically during the physical examination manoeuvres described above. Dynamic alignment and flexibility may differ from those in the static situation and may be more closely related to the development of overuse injuries. Dynamic flexibility is determined by muscle stiffness, freedom to move and muscle strength. Unfortunately, assessment of both dynamic alignment and dynamic

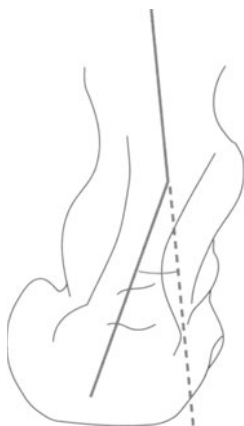


Fig. 3. Subtalar joint varus/valgus is assessed by measuring the acute angle formed by the Achilles tendon and the vertical axis of the calcaneus.

flexibility requires video analysis and thus is restricted to the research setting.

Overall ligamentous laxity can be assessed using the 9-point scale devised by Carter and Wilkinson^[5] and modified by Beighton et al.^[6] The 5 elements of the scale are scored as 'yes' or 'no' and are:

- passive opposition of the thumb to the flexor aspect of the forearm (2 points, 1 point per hand)
- passive hyperextension of the 5th metacarpal phalangeal joint beyond 90° (2 points, 1 point per hand)
- hyperextension of the elbows by 10° or more (2 points, 1 point per arm)
- hyperextension of the knees by 10° or more (2 points, 1 point per leg)
- forward flexion of the trunk with knees extended and palms flat on floor (1 point).

All elements are added to give an overall ligamentous laxity score ranging from 0 (tight) to 9 (hyperlax). Ligamentous laxity has been associated with an increased incidence of overuse injuries in a large group of college physical education students^[7] and with an increased incidence of acute injury in several studies.^[8-10]

3. Lower Extremity Overuse Injuries

3.1 Knee Extensor Mechanism Disorders

The knee extensor mechanism is one of the most common sites for overuse injury in athletes. Overuse injuries of the extensor mechanism include patellofemoral stress syndrome (PFSS), patellar tendinitis or insertional tendinopathy (jumper's knee) and quadriceps tendinitis. Other extensor mechanism disorders, such as patellar subluxation and dislocation, are not necessarily related to repetitive microtrauma but may be exacerbated by overuse.

PFSS (also known as patellofemoral pain syndrome and anterior knee pain syndrome) is common in adolescent and young adult athletes. Affected individuals experience anterior knee pain when the knee is loaded in a flexed position. Ascending and descending stairs or sitting with the knees flexed for a prolonged period of time is painful. On

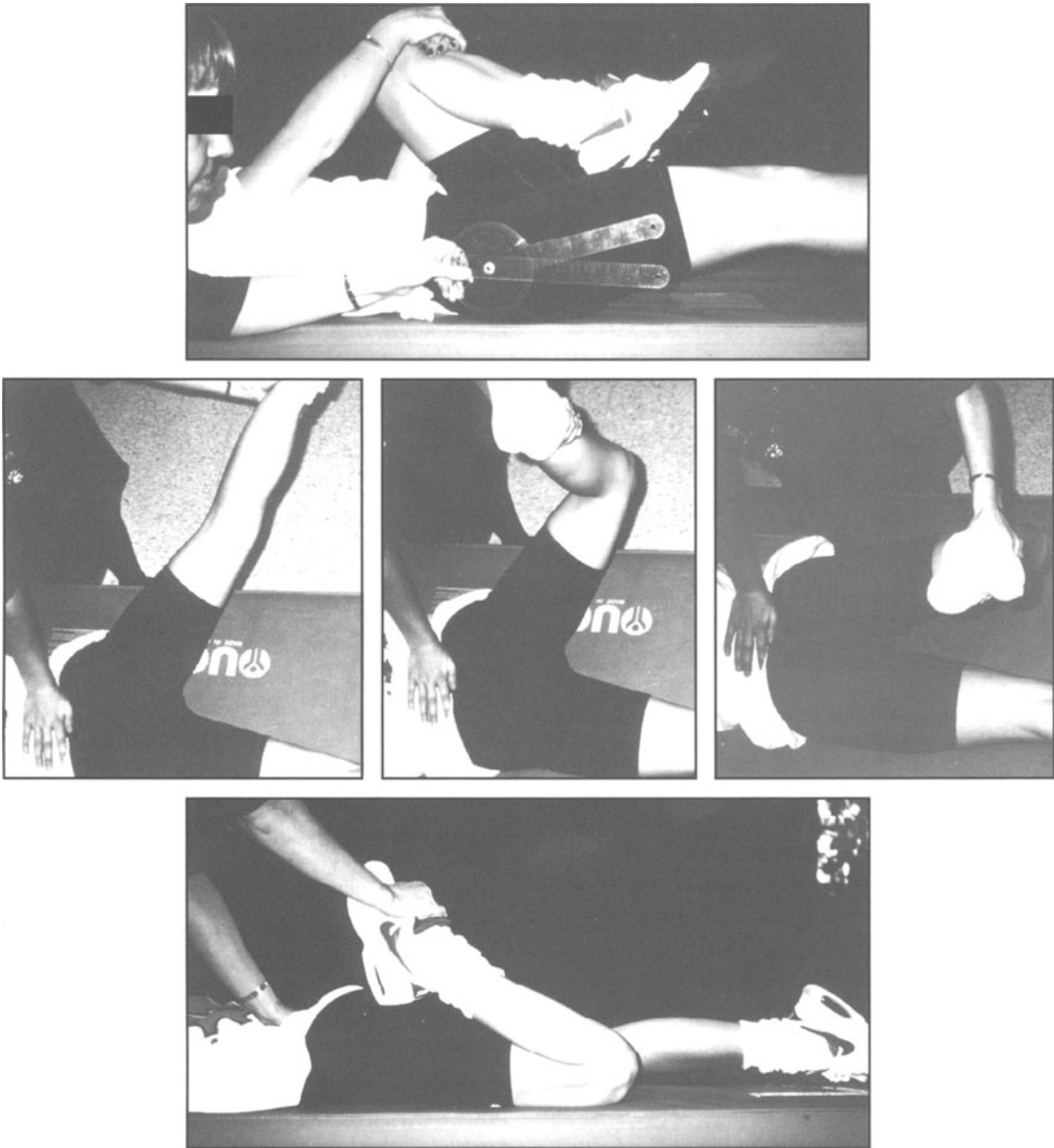


Fig. 4. The Thomas test assesses iliopsoas flexibility (**top**). The athlete is asked to hold one knee flexed to the chest while extending the other hip and knee. In the absence of iliopsoas tightness, the extended leg should rest comfortably on the examining table. The Ober test assesses iliotibial band flexibility (**middle**). A modified form of the traditional test, eliminating the assistance of gravity, is depicted here. The leg to be tested is abducted while the athlete is prone (**left**). The knee of the abducted leg is flexed 90° and the hip is extended (**centre**). The leg should freely adduct to midline from the position in the middle photograph if the iliotibial band is flexible (**right**). The Ely test assesses rectus femoris flexibility (**bottom**). With the athlete prone and the pelvis stabilised against the examining table, the knee is flexed until the heel touches the buttock. If this manoeuvre can not be performed without flexing the hips and/or lifting the pelvis, the rectus femoris muscle is tight.



Fig. 5. Measurement of the popliteal angle assesses hamstring flexibility. With the athlete supine, the hip is flexed 90° and the knee extended as much as possible. A goniometer is used to measure the angle between the lower leg and vertical.

examination of the knee, patellar compression and palpation of the facets or retinacula of the patella reproduce the athlete's pain. The pathology responsible for PFSS is unclear. PFSS frequently was called chondromalacia patellae in the past, implying articular cartilage destruction as a source of pathology. However, arthroscopic studies have not revealed true chondromalacia, other than slight softening of the patellar articular cartilage, in most cases. The term chondromalacia patellae has thus been abandoned in favour of PFSS, patellofemoral pain syndrome, or anterior knee pain syndrome, which do not imply aetiology.

Most authorities agree that anatomical factors play a key role in the development of PFSS. One author has stated that 'if a careful enough search were possible, nearly all patellofemoral disorders

would be found to be related to anatomical predisposition'.^[11] A multitude of anatomical factors have been implicated, and debate continues as to which are most important. The miserable malalignment syndrome consisting of increased femoral anteversion, tibia vara, external tibial torsion and pronation of the feet is frequently blamed for PFSS^[12] (fig. 6). Individuals with this anatomical configuration have an increased Q angle which encourages lateral tracking of the patella.^[13] The increased pelvic width of women further increases the Q angle and may explain the increased frequency of PFSS in female athletes. Children with 'miserable malalignment' have been thought to develop lateral tibial torsion to compensate for increased femoral anteversion. However, we found that children with increased femoral anteversion actually had less lateral tibial torsion as adults than did a control group of adults with normal femoral anteversion.^[14] Thus, lateral tibial torsion is probably unrelated to increased femoral anteversion. The combination of increased femoral anteversion and lateral tibial torsion, however, disrupts normal patellofemoral mechanics predisposing athletes to develop PFSS.^[15] Genu varum and tibia vara have been implicated because they require excess pronation in order for the foot to achieve a plantigrade position. Pronation of the foot causes internal tibial rotation, further disrupting patellofemoral biomechanics.^[16,17] Internal rotation of the tibia actually decreases the Q angle, so the roles of excessive pronation and increased Q angle in PFSS are somewhat contradictory, but both may increase the tension on the medial side of the knee, especially the retinaculum. Internal rotation of the tibia may promote further internal rotation of the femur simulating increased femoral anteversion.^[16] Other anatomical factors associated with PFSS are patella alta,^[13] patellar shape,^[18] the shape of the femoral intercondylar notch, ligamentous laxity and flexibility deficits in the quadriceps, hamstrings and gastrocnemius.^[14,19-21]

Several studies have attempted to sort out this confusing array of anatomical factors, but much work remains to be done before PFSS is fully un-

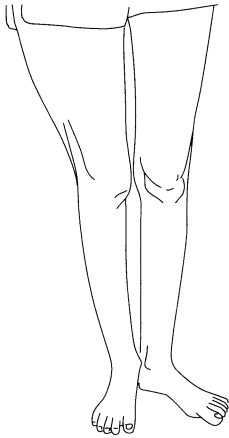


Fig. 6. The miserable malalignment syndrome consists of increased femoral anteversion, secondary external tibial torsion and pronation producing a knock-kneed appearance and predisposing to the development of patellofemoral stress syndrome.

derstood. We found a 30% incidence of PFSS in a population of adults with increased femoral anteversion as compared with a 9% incidence of PFSS in a matched population with normal anteversion.^[14] Reider et al.^[22] found an increased incidence of inward facing patellae in young athletes with PFSS, suggesting that increased femoral anteversion predisposes to PFSS. On the other hand, Fairbank et al.^[23] did not find any relationship between increased femoral anteversion and PFSS. While the work of some authors^[22,24] supports the association between increased Q angle and PFSS, the work of several other authors and our own work do not.^[14,21,23,25,26] Some have reported an association between patella alta and PFSS^[13,27] while others^[19,23] have not found any association. Kujala et al.^[25] also reported an association between ligamentous laxity and PFSS that was not found in earlier work by Reider et al.^[22] or Fairbank et al.^[23] In our work and that of Kujala et al., increased height, but not increased weight, is associated with PFSS in men.^[14,25] The anatomical explanation for this is not clear.

Patellar tendinitis, or jumper's knee, is both a tendinitis and an insertional tendinopathy affecting the insertion of the patellar tendon into either the inferior pole of the patella or, less commonly, the

tibial tubercle. This extensor mechanism disorder occurs in athletes involved in excessive jumping or kicking, e.g. basketball players, volleyball players, figure skaters, gymnasts, soccer players. The role of anatomical factors in predisposing the athlete to jumper's knee is not as well established as it is for PFSS. Training regimen and playing surface are also significant risk factors. Kujala et al.^[19] reported an association between both patella alta and leg length inequality (with the longer leg most often symptomatic), and jumper's knee. In their study, several athletes with jumper's knee had excessively tight hamstring muscles. We have also noted an association between rectus femoris inflexibility and jumper's knee.^[21] Ferretti^[28] was unable to identify any relationship between genu varum or valgum, femoral anteversion, patella alta or foot type and jumper's knee, but did note that more than half of her athletes with jumper's knee had increased Q angles. However, in contrast to the work by Kujala et al., Ferretti did not compare her athletes with jumper's knee with any control group.

PFSS responds well to a nonsurgical treatment programme consisting of training modification and a flexibility and strengthening programme. Jumper's knee responds to a similar programme but with a somewhat lower success rate. Although bony anatomical factors predispose athletes to these disorders, surgical correction of malalignment is very rarely indicated. Occasionally, athletes with the most severe angular or rotational malalignment may appropriately consider surgical correction by osteotomy. Athletes with bony anatomical characteristics predisposing them to develop extensor mechanism disorders should be identified, however, so that preventive flexibility and strengthening programmes may be instituted to decrease the risk of overuse injury. Improving quadriceps, hamstring and gastrocsoleus flexibility and vastus medialis strength and endurance help prevent these disorders. Eccentric strengthening of the quadriceps and ankle dorsiflexors is especially helpful in the treatment of jumper's knee. Space does not permit a detailed description of the rehabilitation programme for extensor mechanism

disorder, but the reader is referred to the work of Smith^[4] for a description of appropriate stretching exercises.

3.2 Iliotibial Band Syndrome

Iliotibial band (ITB) syndrome is a common overuse injury in runners and cyclists. Athletes experience knee pain over the lateral femoral condyle, approximately 2cm above the joint line, that is aggravated by running downhill or by any other activity which places the knee in a weight bearing position at approximately 30° of flexion. The ITB is a thick band of fascia into which the tensor fasciae latae and gluteus maximus muscles insert proximally. Distally, the ITB inserts into Gerdy's tubercle on the lateral aspect of the proximal tibia. With the knee extended, the ITB lies anterior to the lateral femoral condyle. As the knee is flexed, the ITB slides over the lateral femoral condyle and, beyond 30 to 40° of knee flexion, lies posterior to the femoral condyle. If the iliotibial band is excessively tight, repetitive friction causes the ITB and its underlying bursa to become inflamed.

Several anatomical factors in addition to ITB tightness predispose the athlete to develop ITB syndrome. These include an excessively prominent lateral femoral condyle, genu varum, pronation and leg length discrepancy.^[29,30] In normal gait, the foot pronates and the tibia rotates internally after foot strike. Both pronation and internal tibial rotation peak 40% of the way through the stance phase. Internal tibial rotation tightens the ITB by moving its insertion anteriorly. When athletes' feet remain pronated throughout a greater portion of stance, the ITB is stressed. Leg length discrepancy aggravates ITB syndrome by producing a lateral pelvic tilt which stretches the ITB over the lateral femoral condyle on the longer side.

Treatment of ITB syndrome involves training reduction, correction of training errors and identification and correction of anatomical factors. Iliotibial band stretching exercises are an important part of the treatment programme. A lift may be used to correct leg length discrepancies greater than 1cm, and orthotics may assist with the correction

of overpronation. A partial surgical resection of the ITB is performed only as a last resort because the ITB is an important anterolateral stabiliser of the knee.

3.3 Medial Tibial Stress Syndrome

Shin splints is a nonspecific term that has been applied to a variety of disorders causing pain in the lower leg. The term medial tibial stress syndrome (MTSS) refers to a specific overuse injury producing an inflammatory soft tissue reaction and pain along the posteromedial border of the tibia in the middle and distal thirds of the leg.^[31] On examination, athletes have a diffuse area of tenderness along the posteromedial border of the tibia. Delayed bone scan images also show a diffuse area of moderately increased radionuclide uptake. These findings help differentiate MTSS from tibial stress fractures, which have a much more focal area of severe tenderness and greatly increased radionuclide uptake on bone scan.

The tissue source of pain in MTSS was long believed to be the origin of the tibialis posterior muscle. However, anatomical studies by Michael and Holder^[32] have shown that the site of pain and increased uptake on bone scan corresponds to the origin of the medial soleus, not the tibialis posterior, on the tibia. The soleus bridge is a tough layer of investing fascia that inserts on the tibial periosteum, and traction at this site may produce a periostitis which has been demonstrated on bone biopsy. The medial soleus is the main dynamic and static controller of ankle plantar flexion and also inverts the calcaneus.^[33] During running, it contracts eccentrically to limit pronation.

The primary anatomical factor associated with MTSS is excessive pronation. Runners with MTSS pronate more at heel strike than those without symptoms of MTSS.^[34] Excessive pronation increases the eccentric work that must be done by the medial soleus. Pronation may be the common end-point resulting from other anatomical problems, such as a leg length discrepancy or a tight Achilles tendon and these problems must also be assessed. Messier and Pittala^[35] assessed leg length, Q angle,

hamstring and ankle flexibility in those with MTSS and did not find these to be significant factors. They identified an association between maximum pronation, maximum pronation velocity and MTSS. Genu valgum and lateral tibial torsion also predispose to MTSS.^[4] Nonanatomical factors which contribute to MTSS are changes in training intensity and changes in footwear, running surface and terrain. Treatment of MTSS should include activity modification, proper footwear, heel cord stretching, strengthening of the tibialis posterior to decrease stress on the soleus and possibly the use of orthotics to address predisposing anatomical factors. Prompt, appropriate treatment of MTSS is important because athletes who are untreated are at increased risk for developing tibial stress fractures.

3.4 Plantar Fasciitis

Plantar fasciitis is an overuse injury commonly seen in those involved in running sports. The plantar fascia is a fibrous connective tissue originating from the medial tuberosity of the calcaneus and inserting on the proximal phalanges. It acts as a truss maintaining the medial longitudinal arch of the foot and assisting with shock absorption during weight bearing activities.^[36] Athletes with plantar fasciitis experience pain at the medial tubercle of the calcaneus and have tenderness with palpation in that area. The tenderness often extends along the entire medial portion of the plantar fascia. Pain is often most severe upon arising in the morning or standing up after prolonged sitting, abates with normal walking and worsens again with extensive weight-bearing activity.

Several anatomical factors have been associated with plantar fasciitis. These include pronation, cavus foot type and leg length discrepancy.^[35,36] Pronation increases the tension placed on the plantar fascia when weight bearing. Achilles tendon tightness often causes compensatory pronation. Kibler et al.^[37] found that the majority of athletes with plantar fasciitis lack more than 5° of ankle dorsiflexion with the knee extended. The cavus foot is often rigid, lacks the ability to absorb

shock and adapt itself to the ground and has a 'windlass effect' increasing the stress on the plantar fascia. Leg length discrepancy may contribute to the development of plantar fasciitis by causing pronation on the side of the short leg. Treatment of plantar fasciitis which addresses these anatomical factors includes heel cord stretching and the use of orthotics designed to either support the medial arch of the pronated foot or to decrease shock and increase the weight bearing area of the cavus foot. Strengthening the intrinsic muscles of the foot may also decrease the stress on the plantar fascia.

3.5 Stress Fractures

Stress fractures in athletes develop when the skeletal system's natural response to loading is overtaxed. Wolff's Law dictates that bone remodels and hypertrophies in response to stress. As part of this process, osteoclastic resorption occurs at the periosteum; if new bone proliferation can not keep up with this resorption, a fracture develops.^[31] One theory concerning the pathomechanics of stress fractures proposes that fractures occur as a result of muscle fatigue which decreases the shock absorbing capacity of the lower extremity. An opposing theory suggests that the repetitive force exerted by muscle on bone is responsible for a fatigue fracture of bone. Most likely, a combination of these 2 mechanisms acts synergistically to produce stress fractures.

The most common site of stress fractures in athletes is the tibia, where 49% of 320 stress fractures occurred in a study by Matheson et al.^[38] The next most common sites were the tarsal bones (25%) and metatarsals (9%). Tibial stress fractures were more common in younger athletes and tarsal stress fractures in older athletes. Two thirds of the athletes in this series were runners, with the other third participating in a wide variety of other sports. The most common type of tibial stress fracture occurs on the posteromedial or compression side of the bone, in either the proximal or the distal third of the shaft. A less common, but more problematic, tibial stress fracture occurs on the tension side of the bone or anterior cortex of the midshaft of the

tibia. This stress fracture heals poorly and often requires surgical intervention to achieve union.

The aetiology of stress fractures is multifactorial with training intensity, bone size, sex, diet, hormonal status and anatomical factors all playing a role. Women have a higher incidence of stress fractures than men,^[39-41] and amenorrhoeic athletes with decreased bone density are particularly at risk. The female athlete triad consists of disordered eating, amenorrhoea and osteoporosis. It is especially common in athletes involved in 'appearance sports' such as gymnastics, figure skating and ballet. A complex multifactorial, incompletely understood relationship exists between amenorrhoea, estradiol levels, bone mineral density and athletic activity. Some amenorrhoeic skaters and gymnasts actually have higher lower extremity bone density than do nonathletic, eumenorrhoeic individuals,^[42-43] possibly as a result of extensive weight-bearing activity. Nevertheless, female athletes with stress fractures should be evaluated for the presence of the triad. Anatomical factors have been studied in association with tibial and tarsal stress fractures but do not appear to be as significant as training intensity and bone density.

Matheson et al.^[38] found that varus alignment (including genu varum, tibia vara, subtalar varus and forefoot varus) was associated with lower extremity stress fractures, 49% of which were tibial. Pronated feet were also associated with tibial stress fractures. As discussed in section 3.3, excessive pronation overloads the medial soleus which may repetitively fatigue the posteromedial tibia. Varus alignment of the knee and/or tibia requires compensatory pronation and thus may contribute to tibial stress fractures by a similar mechanism. The anterior cortex tibial stress fracture occurs mainly in athletes involved in sports requiring repetitive jumping, and it has been suggested that repetitive contraction of the posterior leg muscles produces a flexion moment which increases tensile forces across the anterior tibial cortex.^[31] Rettig et al.^[44] have suggested that the shape of the tibia may be a risk factor for this type of fracture with the normal anterior bowing being a predisposing factor. A Q

angle of greater than 15° increased the risk of stress fracture in male army recruits, but the location of the stress fractures was not identified.^[45]

The association between stress fractures in the foot and anatomical factors has not been proven.^[46] A short first metatarsal, metatarsus adductus, limited ankle dorsiflexion and subtalar motion may concentrate stress on the navicular and predispose it to stress fracture.^[47] Matheson et al.^[38] found an association between pronation and tarsal bone, but not metatarsal stress fractures, and an association between cavus feet and metatarsal stress fractures. Presumably, the rigid cavus foot is less able to absorb shock, resulting in excessive loading of the metatarsals. Morton's foot, which describes a short first metatarsal, proximally displaced sesamoids and a hypermobile cuneiform first metatarsal joint, has also been implicated in the aetiology of tarsal and metatarsal stress fractures.

Upper extremity and axial (i.e. spondylolysis and rib) stress fractures have not been associated with any predisposing anatomical factors. Spondylolysis, a stress fracture of the pars interarticularis, is the most commonly occurring stress fracture in athletes outside the lower extremity. It occurs most frequently in adolescents participating in sports such as gymnastics, diving and figure skating which require repetitive lumbar hyperextension.

3.6 Paediatric Considerations

All of the overuse injuries discussed thus far occur in children as well as adults. Adolescents are especially prone to develop overuse injuries during their growth spurt. Longitudinal bone growth occurs at a more rapid rate than does muscle elongation. Inflexible muscles produce 3 general types of problems:

- pain on the opposite side of the joint (i.e. hamstring tightness causing anterior knee pain)
- overuse syndromes related to excessive pressure (i.e. iliotibial band syndrome)
- traction apophysitis.^[4]

Preparticipation physical examinations performed on paediatric and adolescent athletes should include flexibility and muscle symmetry or

balance assessment so that appropriate prehabilitation programmes can be prescribed.

Traction apophysitis is an overuse injury unique to adolescent athletes with open growth plates. Tendons and bones unite at the apophyseal growth cartilage. When subjected to repetitive micro-trauma and excessive traction, painful bony and cartilaginous overgrowth occurs at some of these sites (i.e. tibial tubercle). Untreated apophysitis predisposes the athlete to avulsion fracture. Although relatively rare, avulsion fractures of the tibial tubercle, anterior superior and inferior iliac spines, lesser trochanter, ischial tuberosity and medial epicondyle do occur. Table III shows common sites of apophyseal injury and eponyms used to describe these overuse injuries. The eponyms can be a source of confusion as some of them have multiple meanings. For example, the term jumper's knee is used for patellar tendinitis in adults and apophysitis of the inferior or superior pole of the patella in adolescents. Similarly, 'Little League elbow' has been used to describe a myriad of elbow injuries in the paediatric population.

The anatomical factors predisposing to traction apophysitis are the presence of open apophyses and muscle inflexibility.^[3-4] We have found that rectus femoris inflexibility is associated with both Osgood Schlatter's disease and jumper's knee in adolescent athletes.^[21] Sever's disease has been associated with both heel cord tightness and excessive pronation.^[48] It is unclear whether pronation itself predisposes to the development of Sever's disease or whether it is merely a compensatory mechanism for the heel cord tightness. Micheli^[3] believes that a painful accessory navicular in adolescents is a form of traction apophysitis related to tibialis posterior muscle inflexibility. This condition may also be related to tight heel cords which cause excessive pronation (personal communication; Smith AD, 1996).

Tarsal coalition (fusion between 2 tarsal bones) is an anatomical variant that often becomes symptomatic in adolescent athletes and may be mistaken for an overuse injury. Tarsal coalition is present in approximately 1% of the population^[49] but is

Table III. Traction apophysitis

Apophysis	Eponym for apophysitis
Lesser trochanter	Iliac apophysitis
Ischium	Ischial apophysitis
Tibial tubercle	Osgood-Schlatter disease
Superior pole of patella	Quadriceps tendinitis (jumper's knee)
Inferior pole of patella	Sinding-Larsen-Johansson syndrome (jumper's knee)
Calcaneus	Sever's disease
Navicular	Accessory navicular syndrome
Base of 5th metatarsal	Iselin's disease
Medial epicondyle	Medial epicondylitis (Little League elbow)
Olecranon	Olecranon apophysitis (Little League elbow)

asymptomatic in the vast majority. The most common coalition is a calcaneonavicular bar, followed by the talocalcaneal bar.^[50] Adolescents with tarsal coalitions generally present with foot and ankle pain or a peroneal spastic flat foot which is aggravated by athletic activity. They may also experience recurrent ankle sprains because of lack of foot mobility; recurrent ankle sprains in adolescent athletes should trigger a search for a tarsal coalition. If temporary immobilisation and the use of orthotics do not relieve symptoms, surgical resection of the tarsal bar may be necessary to allow these athletes to return to full pain-free activity.^[51] Adolescents probably become symptomatic as the tarsal coalition ossifies and, once ossification is complete, may have no further problems.

3.7 Pronation and Orthotics

Pronation and foot malalignment are implicated in a variety of lower extremity overuse injuries. A series of 180 runners with overuse injuries reported a 58% incidence of pronation in the study by James et al.^[1] A study of plantar pressures in athletes during running found that those with cavus feet had significantly greater load on the forefoot than those with other foot architectures.^[52] Athletes with either cavus or planus feet had more overuse injuries than those with normal feet.

Orthotics are often prescribed to correct pronation or foot malalignment, but whether they actually achieve these goals is debatable. Foot or-

thotics can be divided into 2 categories: functional and accommodative.^[53] Functional orthotics attempt to realign the foot by placing the subtalar joint in a neutral position. They are constructed of a rigid or semirigid material that will maintain the foot in the desired position. Accommodative orthotics are prescribed to improve weight distribution by bringing the support surface up to meet the foot. These orthotics are fabricated from a softer material that will mould to the foot and accommodate deformities. Accommodative orthotics are generally prescribed for treatment of cavus feet to distribute pressure over a greater surface area. Some feet are treated best with a hybrid of the functional and the accommodative orthotic.

Kilmartin and Wallace^[54] reviewed the literature on functional foot orthotics and concluded that they have little effect on knee motion or alignment but do reduce rearfoot movement. Studies of the effect of orthotics on knee alignment have shown that orthotics may reduce the static Q angle but do not alter the dynamic Q angle. In addition, orthotics affect the knee differently in walking and running. Orthotics have been shown to decrease both maximum pronation and the velocity of rearfoot movement^[55] which theoretically decreases the work required by supinating muscles such as the medial soleus. This reduction in workload should benefit those with overuse injuries related to medial soleus overload, such as MTSS and tibial stress fractures. On the other hand, no research has proven the advantage of placing the foot in a supinated position.^[54] Orthotic prescription is based on the clinical determination of subtalar joint neutral position, and no objective, repeatable method for determining the neutral point has been devised.

In summary, orthotics may be useful in the treatment of overuse injuries in which excessive pronation is thought to be an aetiological factor, but firm evidence of benefit is lacking. Subjectively, orthotics appear to be beneficial; 78% of the runners in the study by James et al.^[1] reported benefit from the use of orthotics. Because orthotics (especially if rigid) may alter the biomechanics and loading of the lower extremity, their use might potentially

contribute to the development of new overuse injuries, including stress fractures. If used, functional orthotics should be one part of a comprehensive treatment programme and not the sole treatment.

4. Upper Extremity Overuse Injuries

4.1 Shoulder

The most common overuse injuries involving the shoulder are instability, impingement and rotator cuff tendinitis. Repetitive overhead or throwing activity plays a primary role in the development of all these disorders. Anatomical factors which may contribute to these injuries have not been widely studied. Shoulder instability develops from chronic microtrauma to the capsule and glenoid labrum or may be seen in athletes with generalised ligamentous laxity. Anterior instability is the most commonly seen form of shoulder instability, and primary anterior instability predisposes the athlete to develop secondary subacromial impingement, i.e. compression of the rotator cuff tendons between the acromion and humeral head.^[56] The normal shoulder translates posteriorly 4mm on the glenoid with maximal humeral abduction and external rotation; tightening of the anterior capsule is responsible for this translation. With anterior instability, the humeral head actually translates anteriorly with full abduction and external rotation allowing impingement to occur. Ligamentous laxity also predisposes to the development of rotator cuff tendinitis. In adolescents, tightness of the posterior shoulder muscles is associated with anterior impingement, especially in competitive swimmers. A prehabilitation programme consisting of stretching of the shoulder external rotators and strengthening of both the rotator cuff and scapular stabilisers may prevent the development of impingement in this population. The shape and slope of the acromion may play a role in the development of rotator cuff disease.^[57]

4.2 Elbow

The majority of elbow injuries in athletes are overuse injuries and include:

- medial and lateral epicondylitis
- radiocapitellar overload syndrome
- valgus-extension overload syndrome resulting in posteromedial olecranon impingement and chondromalacia
- olecranon stress fracture
- a variety of tendinitises.^[58]

Other than rupture or stretching of the ulnar collateral ligament, which allows increased valgus and radiocapitellar joint compression, no anatomical factors have been associated with elbow overuse injuries. The normal ulnohumeral joint has an average carrying angle (ulnohumeral valgus with the elbow fully extended) of 10 to 15° and is usually greater in women than in men. The relationship between carrying angle and elbow overuse injuries has not been studied, but it seems logical to hypothesise that an increased carrying angle would predispose to all overuse injuries in which valgus stress plays a role. Professional baseball pitchers often have cubitus valgus and bony hypertrophy which narrows the olecranon fossa predisposing them to posteromedial impingement of the olecranon.^[59]

5. Conclusions

Overuse injuries have become increasingly prevalent in both the adult and paediatric athletic populations with the increasing tendency of athletes to participate in a single sport to the exclusion of others. Training regimen, biomechanics and other extrinsic factors contribute to the development of overuse injuries. Some athletes, because of their unique anatomical structure, appear to be predisposed to develop these injuries. Both anatomical malalignment and soft tissue factors such as muscle inflexibility, ligamentous laxity and muscle imbalance contribute to this predisposition. Although cause and effect have not been definitively proven, multiple studies have shown an association between soft tissue factors and overuse injuries. Given this association, soft tissue factors must be properly rehabilitated to prevent persistence or recurrence of the overuse injury.

Some athletes with severe malalignment compete successfully at a high level without being plagued by an excessive number of overuse injuries. Thus, an anatomical predisposition to develop overuse injuries should not discourage athletic participation. Instead, it should be viewed as a warning to pay extra attention to developing an appropriate training regimen, utilising proper biomechanics in the chosen activity, and maintaining good flexibility and strength.

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