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Biomechanical Evaluation of the Dancer

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Dance injuries are seldom caused by one single trauma or physical factor; rather they are usually the result of repeated overload and microtrauma superimposed on multiple biomechanical factors. A sound biomechanical evaluation is essential to providing complete treatment for the dancer. Although seemingly the epitome of fitness, dancers present with many strength and flexibility imbalances that can contribute to a sequelae of pathologies.

The drive and mental discipline of the dancer must not be overlooked when treating this population. A dancer has been trained to view the body as his or her tool of expression. Concepts such as "more is better" and "work through the pain" have been drilled into dancers' psyches over years of training, often beginning at a young age. If you give a dancer an exercise without restrictions on the repetitions, do not be surprised if at your next visit the dancer reports doing the exercise 100 times every hour since you last met. A practitioner's greatest challenge may be to communicate the importance of rest for overuse injuries and that sometimes "less is best." It is often extremely difficult for dancers to accept their injuries. A dancer's body is his or her livelihood, and injury can mean lost wages or even the end of a career. Care must be taken to address these overlying issues when treating dancers.

Besides the high physical demands of dance, other external and environmental factors may play a role in the incidence of injury. Current theory proposes that a chronic state of dehydration may be associated with decreased viscoelastic properties of connective tissue that can result in local microtrauma.[3, 11] During long hours of rehearsal, dancers' intake of fluids may not be as great as their output, a common contribut-

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ing factor to dancers' susceptibility to overuse injuries. Inappropriate footwear or lack of footwear altogether can lead to various foot conditions and abnormal lower kinetic chain biomechanics. Different dance surfaces and stages may also contribute to acute injuries as well as overuse injuries. Many dancers performing on Broadway dance on what is termed a *raked* stage, in which the back of the stage is actually up to 15 degrees higher than the front. This rake effectively makes the dancers perform on a hill. Adding to this is the costuming of high heels, long hours of practice, and repetitive movement. All of these factors contribute to the stresses that are applied to the dancer's closed kinetic chain from the foot up to the vertebral column.

The literature indicates that 65% to 80% of dance injuries occur in the lower extremity, 10% to 17% occur in the vertebral column, and most remaining injuries occur in the limb (5% to 15%).[17] As such, this article focuses on the biomechanical evaluation of the dancer's lower extremity and vertebral column.

EVALUATION OF THE HIP

Dancers appear to represent the epitome of grace and flexibility. That grace comes at a price, however. Dancers work continually on repetitive motions that predispose them to overuse injuries and muscle imbalances. This muscle imbalance is most apparent at the hip joint, where extreme range of motion in flexion, external rotation, and abduction is emphasized. Dancers' training is directed to increasing the strength of the hip abductors and external rotators with increasing flexibility of the adductors. Conversely, strength of the adductors and the flexibility of the abductors and external rotators are often neglected. Reid[22] demonstrated that ballet dancers have significantly less internal rotation and adduction than nondancers and significantly greater external rotation and extension than nondancers. These trends toward asymmetric flexibility patterns increased in the older dancer. The positions of adduction and internal rotation are rarely assumed in dance warm-ups or performance (with the possible exception of modern dance).[17, 22] Many have correlated that the decrease in internal rotation and adduction is reflected in the adaptive shortening and extreme tightness in the abductor muscles and the iliotibial band.[17, 22, 29] This leads to stretch weakness of antagonistic muscle groups that control internal rotation and adduction.[12] In addition, it has been theorized that adaptive shortening of the lateral hip joint capsule and external rotators occurs, thus limiting internal rotation.[17]

One of the most important factors of classical ballet is proper turnout or external rotation. Ideally, turnout is achieved mainly by maximum external rotation at the hip, with some contribution from the knee, ankle, and foot joints. The unusually large range of external rotation in dancers is the result of bony and soft tissue adaptations. After age 11, the femoral neck can no longer be altered through the molding process of continual pressure into a preferable retroverted position.[17, 27] For dancers after age 11, progression and maintenance of external rotation must be accomplished through stretching of the appropriate soft tissues. In dance, external rotation at the hip is usually gained at the expense of adaptive shortening of the external rotators, lateral hip capsule, abductors, and iliotibial band, whereas the internal rotators and adductors suffer from stretch weakness. The imbalance in these force couples sets the stage for dysfunction at the hip.

Snapping Hip

The snapping hip is a frequent phenomenon among dancers. According to a 6-year survey by Reid and colleagues, the snapping hip was the most frequent complaint by ballet dancers (44%); however, only about one third of these dancers had pain associated with the snapping.[23] Snapping hip occurs anteromedially or laterally. It is important that the anterior or medial clicking hip is distinguished from the lateral problem.

Lateral Snapping Hip

Lateral snapping is frequently due to the iliotibial band rubbing over the greater trochanter.[13, 19] Milan reports that the lateral clicking frequently occurs in the supporting lower extremity with movements of rotation.[17] This problem tends to occur if the dancer is "sitting in the hip" (allowing the pelvis to drop on the contralateral side with the ipsilateral hip adducting) because he or she has insufficient abdominal or abductor strength.[13] "Sitting in the hip" can also be caused by weak abductor and external rotator muscles.[13] Although pain is rarely associated with snapping hip and it is generally benign, the fault must be corrected because degeneration of the greater trochanter has been suggested when the snapping occurs over a long period of time.[19] Surgical release of the fascia lata at the greater trochanter is rarely indicated. Contributing biomechanical factors to the lateral clicking hip are thought to include tight lateral hip muscles and iliotibial band, narrow interiliac width, muscle imbalance with weakened internal rotators and adductors, and adaptive shortening of abductors such as gluteus medius and tensor fascia lata.[17, 22] *Biomechanical evaluation may reveal* a positive Ober test, decreased hip adduction, limited internal rotation at the hip, and weak hip adductors.

Anterior or Medial Snapping Hip

A deep snap or click that occurs anteriorly or medially in the groin can be caused by motion of either the iliofemoral ligament over the femoral head or the iliopsoas tendon over anterior-inferior iliac spine or the lesser trochanter.[13, 17, 19, 22, 29] Taunton et al found the snap occurred primarily when the leg is descending from a position of full abduction and external rotation.[29] The medial clicking phenomenon occurs equally in weight bearing and non–weight bearing when attempting movements of rotation. This snapping can lead to aggravation of the iliopsoas tendon and muscle strain. Iliopsoas strain can also be caused by poor trunk posture. The iliacus portion of the muscle passes under the inguinal ligament and attaches at the lesser trochanter. The *développé* maneuver in ballet places the hip in a flexed, externally rotated, and abducted position so that the iliacus muscle makes a U under the inguinal ligament. If the pelvis is not held in the correct position but is allowed to tilt laterally "sitting in the hip," the space for the iliacus to exit the pelvis is even further narrowed.[13] *Biomechanical evaluation may reveal* a positive Thomas test for hip flexor tightness, palpable clunk or snap anteromedially with descent from abduction and external rotation, or flexion and external rotation in supine or weight bearing.

EVALUATION OF THE KNEE

Knee injuries account for 14% to 20% of all ballet injuries.[17, 22, 29] Findings are consistent that peripatellar pain is reported to be the most common knee condition.[17, 22] Specific diagnoses of peripatellar pain include chondromalacia patellae, synovial plica syndrome, laterally subluxing patella, bursitis, and patellar stress fractures. There are many contributing factors to the mechanisms of knee injury, including deep knee bends (pliés), repetitive jumping (sautés), inadequate footwear, poor dance surfaces, muscle imbalance and inadequate strength, long hours of practice during growth spurts, and forced turnout.[12, 22]

In the ideal turned-out position, the weight should fall along a plumb line from the body to the middle of the thigh, knee, and ankle. The correct distribution of weight is achieved by the external rotation at the hips (Fig. 1*A*). Unfortunately, because often adequate hip external rotation is lacking, many dancers achieve a turned-out position by what is termed "screwing the knees."[17, 22, 29, 30] This phrase describes placing the feet at 180 degrees of external rotation while the knees are bent and then straightening the knees while the feet remain firmly fixed on the floor (Fig. 1*B*). This puts a great deal of torque on the knees and can produce medial knee strain and patellar subluxation.[30] Before being properly warmed up, the ballet dancer often forces the tibia into external rotation with respect to the femur as the knee is extended. Strain is placed on the medial collateral ligament, menisci, and capsule.

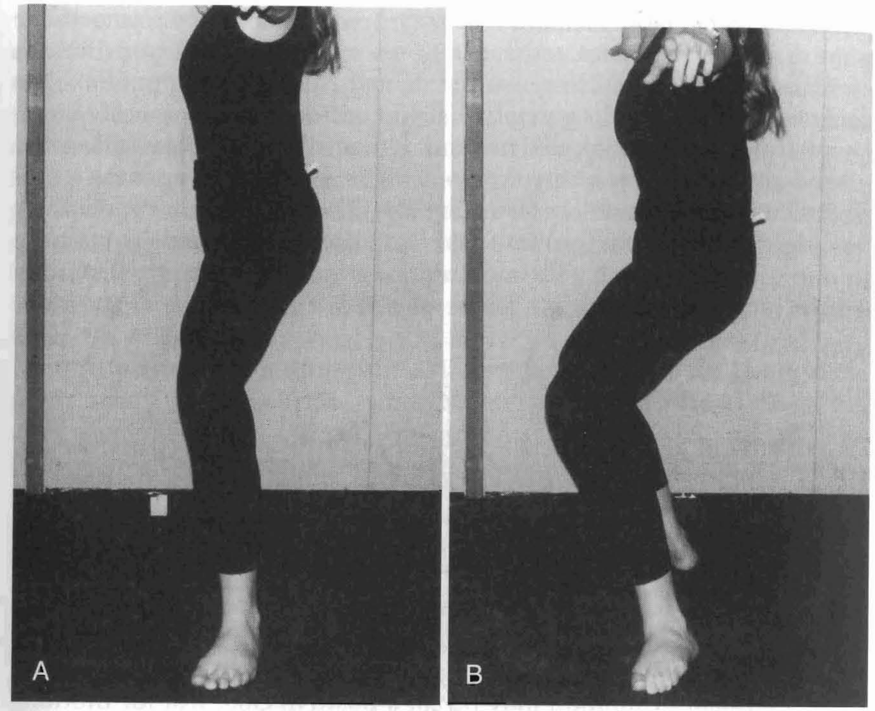

Figure 1 *A,* Dancer with correct turned-out position, achieved by external rotation at the hips. *B,* Dancer achieving turned-out position by "screwing the knees."

Patellar Tendinitis

Patellar tendinitis can be associated with Osgood-Schlatter disease in the ballet dancer.[17, 22] The precise pathology of this syndrome is still unclear, but one possibility is the explosive pull of the quadriceps during a leap or other repeated trauma leading to the acute tearing of some of the superior fibers of the patellar tendon just inferior to the lower pole of the patella. This microscopic rupture leads to chronic inflammation, with a small nodule of granulation tissue about the size of a grain of wheat lying within the tendon.[13, 17] Knee and foot malalignment because of forced turnout and pronation are factors that may lead to the increasing load of the patellar tendon in ballet dancers. Patellar tendon injury can help be prevented through adequate eccentric strength and control of the gluteal and calf muscles in landing from jumps or leaps. Other factors that may predispose dancers to patellar tendon injury include a reduced plié or reduced dorsiflexion from a short Achilles tendon. Because the dancer cannot fully dorsiflex, the eccentric load of landing must be absorbed in a short space of time.[13] Quadriceps inflexibility also commonly contributes to patellar tendon disorders. *Biomechanical evaluation may reveal* shortening of the quadriceps and hip flexors as tested by the Thomas test or prone Ely's test, tight Achilles tendon with restricted dorsiflexion, and pain at the inferior patellar tendon with maximal quadriceps contraction or landing from a jump.

Iliotibial Band Syndrome

Iliotibial band syndrome accounts for nearly 11% of knee problems in Reid's data on dancers.[22] In view of the frequent marked tightness of the iliotibial band in dancers, it is surprising that this overuse syndrome is not more common. It may be of some assistance to dancers that they spend much of their practice and performance time with their hips in abduction and external rotation, which tends to decrease the tension on the iliotibial band over the bony prominences, both at the hip and the knee. Dancers complain of pain at the lateral knee with this disorder. *Biomechanical evaluation may reveal* a positive Ober test for iliotibial band tightness and a positive Noble's compression test.

Patellofemoral Joint Syndrome and Anterior Knee Pain

Dancers commonly present with pain along the medial side of the knee and patella, without a history of specific injury.[13] There is no history suggestive of internal derangement, and examination is often unremarkable. A key examination technique is to ask the dancer to do a plié, especially in fifth position, and observe for "screwing of the knees" that predisposes the patellofemoral joint to problems. Dancers may complain of pain at the medial knee and behind the knee cap, stiffness with prolonged immobility, and pain during a part of the range of the extension arc. Pain is also present with stair climbing, squatting, or kneeling because all the activities cause the knee cap to rub against the femur. Frequently a grinding sensation or crepitus is felt with active movement. Some jazz and modern dancers may participate in excessive floor work requiring them to be weight bearing through their knees. The compressive forces of kneeling may irritate the patellar bursa and cause similar symptoms. Simply wearing knee pads for floor work can be helpful in reducing the compressive forces at the patella.

It should be noted that in ballet, slight knee hyperextension is aesthetically desirable. Because of a more anterior placement of the trunk and upper body, it shifts the center of gravity anterior to the knee; this produces a more pleasing line on point, a gentle S curve rather than a straight line. Unfortunately, hyperextension places more compressive forces anteriorly on the patella. This problem can be helped by a program of proprioceptive training to allow the dancer to get the feeling of using the quadriceps to "pull up" rather than pushing the knee back in the weight-bearing position. It may be useful to reinforce the concept of "pulling up the thigh" rather than "pushing back on the knee."

In studying the mechanism of injury for the knee, the quadriceps performance is an important factor. Milan reported studies on the isokinetic characteristics of the quadriceps muscle in professional dancers. Data showed that at peak season, the relative quadriceps torque measured for the male ballet dancers was 98% of the weight-predicted figure, and for females it was only 77%.[17] This suggests that despite their increased quadriceps strength into the season, female dancers were still performing with suboptimal quadriceps strength. A decrease in quadriceps strength and function has been implicated in many disorders of the patellofemoral joint.[13, 17, 22] In particular, the strength and development of the vastus medialis oblique fibers of the quadriceps is important in the medial tracking of the patella. It has been shown that adductor strength plays a key role in the strength and function of the vastus medialis oblique.[10, 12] Because dancers tend to present with overstretched and weak adductors, decreased quadriceps function, increased compression, lateral and rotational forces on the patella, tight iliotibial band, hyperextended knees, and long hours of practice, they are unfortunately predisposed to this disorder. *Biomechanical evaluation may reveal* genu recurvatum or valgum; increased Q-angle; tibial bowing with external torsion; increased pronation in standing or in gait; decreased medial glide of the patella; decreased vastus medialis oblique or quadriceps strength; decreased adductor strength; and positive McConnell, Ober, Thomas, and Ely's tests.

Ligament and Meniscal Injuries

As previously described, dancers tend to compensate for poor turnout by "screwing the knees." This places a tremendous amount of rotational strain on the knee ligaments, specifically, the medial collateral ligament and the medial menisci.[19, 22] There appears to be some chronic attenuation and stretching of the medial ligamentous structures as well as the posterior capsule. Miller's explanation is accepted by most authors.[22] He showed that most females begin dancing between the ages of 4 and

8 years. By contrast, males frequently become interested in dance at age 15 to 16 on average. Miller also noted that several dancers who began performing at an older age demonstrated significant laxity of the knee ligaments to allow some rotation of the tibia when the knee was extended. The laxity in dancers' knees beginning after age 15 was thought to be related to the absence of sufficient hip external rotation and compensation at the knee. Although it would seem that this would set dancers up for a disproportionately high incidence of meniscal lesions, in fact, meniscal lesions appear to form only a small percentage of the knee injuries. Rovere and associates[24] reported only one case, and Washington[32] recorded seven verified and six unverified cases. Although these lesions undoubtedly do occur, they may be less common than expected. *Biomechanical evaluation may reveal* positive results for standard orthopaedic tests for ligamentous and meniscal injury, including Lachman test, Apley's compression and distraction test, McMurray test, and varus/valgus stress.

EVALUATION OF THE LOWER LEG

Lower leg problems constitute 5% to 8% of ballet injuries, with the most common problem being shin splint syndromes.[17] Lower leg syndromes in ballet dancers have a multifactorial origin, as do most dance injuries. Dancing on a hard, non–shock-absorbing surface, dancing in unsupporting shoes or no shoes at all, and dancing without sufficient warm-up are all important factors that contribute to lower leg pathologies.

Tibial bowing or varum has also been associated with lower leg pathologies. Dancers who began training at a young age may also present with tibial bowing (varum) from the consistent positioning of the lower extremity in external rotation. It is hypothesized that the shape of the tibia, similar to the head of the femur, can be influenced before the age of 11.

Incorrect turnout has also been cited as another contributing factor of lower leg problems. With a lack of sufficient external rotation at the hip, increased compensation of external rotation at the knee, ankle, and foot results. Subsequent "rolling in of the foot" then occurs (hindfoot eversion, forced pronation of the midfoot and forefoot) (Fig. 2). Rolling in places an additional strain on the muscles controlling pronation (tibialis anterior, tibialis posterior, and the medial half of soleus) and may precipitate a lower leg syndrome.[17]

Calf strain is a common occurrence in certain dancers who work with their body weight back rather than centered over the foot. These dancers do not use their quadriceps adequately and rely excessively

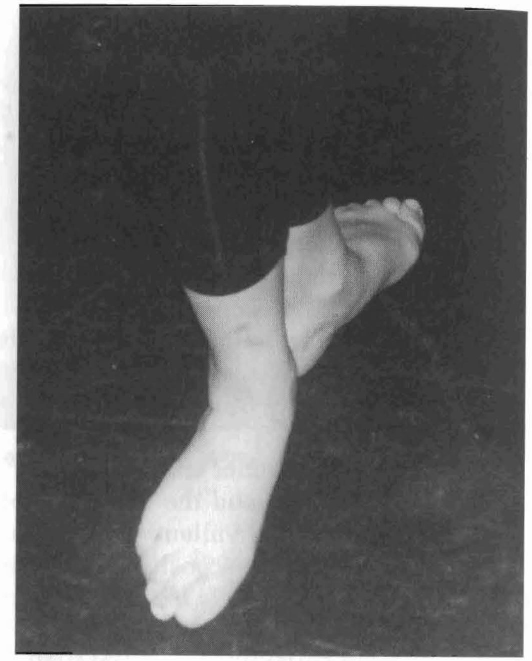

Figure 2 Rolling-in of the foot with hindfoot eversion and forced pronation of the midfoot and forefoot.

on gastrocnemius and soleus strength to control knee flexion and extension via the closed kinetic chain.[13]

Lateral Shin Pain

Lateral shin pain is seen most commonly in those dancers with tibial bowing and those who have decreased turnout. The result is that dancers tend to force the ankle into eversion and overuse the peroneal muscles to achieve a lower leg alignment that appears straight. Lateral shin pain can also be due to fibular stress fracture, which manifests with pain and pinpoint tenderness at the junction of the upper three quarters and the lower quarter of the fibula.[13] Bone scans and roentgenograms are the most effective in making a differential diagnosis and must not be delayed because the longer a dancer continues to work with a stress fracture, the longer it takes to heal.[19, 25] *Biomechanical evaluation may reveal* bilateral tibial bowing (varum), increased rearfoot valgus when weight bearing in first position, and painful and weak resisted eversion.

Medial Tibial Stress Syndrome

Medial tibial stress syndrome (MTSS), a term originally selected by Drez, denotes the symptom complex otherwise known as shin splints.[28]

MTSS is defined as regular or long-lasting pain, which occurs only at the medial surface and distal two thirds of the shank without any signs or symptoms of stress fracture, such as pain and swelling of the tibia.[28] Muscle imbalance sets the stage for relative joint contracture at the ankle that does not allow for adequate absorption of eccentric loads from jumping and stomping. Altered osteokinematics of the knee, ankle, or foot may require that a segment compensates by absorbing a greater eccentric load. Even a change in footwear can precipitate events that lead to unaccustomed energy dissipation and tissue overuse. Although there is some disagreement in the literature as to the specific cause of shin splints, many authors have indicated that a major precipitating factor is unaccustomed eccentric action of the plantar flexors (the soleus in particular), as in controlling dorsiflexion when landing from a jump.[13, 17, 19, 28]

The work of Sommer and Vallentyne[28] demonstrated a correlation between foot posture and the incidence of MTSS. It has been demonstrated by Sommer and Vallentyne that a qualitative assessment of static foot posture confirmed a positive relationship between pronation and shin splints. Either forefoot or hindfoot varus alignment correlated with the frequency of MTSS. Furthermore, the combination of forefoot and hindfoot varus tendency was synergistic.[28] Other factors, such as gastrocnemius/soleus contracture or tibia varum, are also well known to produce hyperpronation. Hyperpronation of the subtalar joint may be the common factor that may be the ultimate mediating mechanism in MTSS. *Biomechanical evaluation may reveal* decreased length of the gastrocnemius and soleus musculature, tibial varum, increased hindfoot and forefoot varus measured with the subject prone in standard subtalar neutral, and increased standing foot angle (>30 degrees) measured while weight bearing as the angle between a line from the medial malleolus to the navicular prominence intersecting with a line from the navicular to the first metatarsal head (similar to Feiss's line) (Fig. 3).

EVALUATION OF THE ANKLE

Ankle problems constitute 15% to 22% of ballet injuries.[17] Of the ankle injuries, the most common is an acute inversion sprain. Other documented ankle conditions include posterior impingement, Achilles tendinitis, and flexor hallucis longus tendinitis. As mentioned in the previous sections on the hip, knee, and lower leg, forced turnout is a major contributing factor to problems at the ankle for the dancer, as are poor floor surfaces, inadequate footwear, and insufficient warm-up. Certainly other contributing factors are the tremendous amount of plantar flexion, dorsiflexion, and other movements of the ankle required in dance.

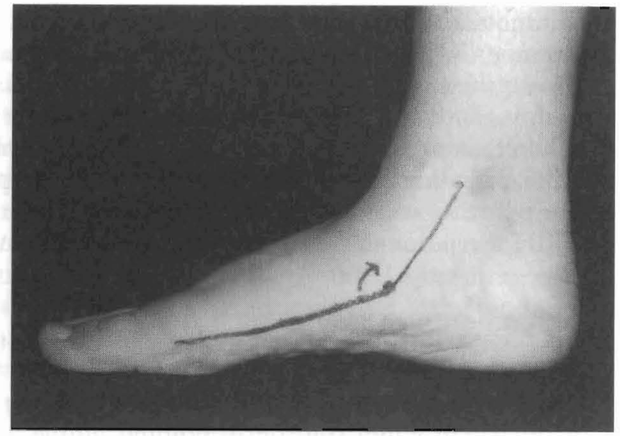

Figure 3 Standing foot angle.

A dancer's technique must not be overlooked as a major contributing factor to overuse injuries. If a dancer is working with hyperextended knees or with the weight back, there is a tendency for the body weight to jam the posterior ankle elements rather than allowing the body weight to fall correctly over the talus, midfoot, and metatarsals.[13] Working with the weight back also increases the load the Achilles tendon must raise when the dancer rises to a demipointe position, and the posterior calf muscles have to work harder to keep the dancer balanced.[13] It is important to remember that if the trunk musculature is not strong enough to hold the dancer over the pelvis, the ankle rocks excessively between inversion and eversion when the dancer is on demipointe or pointe thus fatiguing the medial and lateral ankle muscle groups.

Inversion Sprain

Inversion ankle sprains damage mainly the anterior talofibular ligament and result from forced inversion and plantar flexion. This may occur during poor landing, during missteps, or while falling off of demipointe (weight bearing on the metatarsal heads).[17] Although choreography is well planned and rehearsed, many dancers are working close to their limits of strength, and a slight loss of concentration or balance can lead to this acute injury. Pain on stressing the ligaments with inversion and plantar flexion usually means an incomplete tear. Radiographs should always be taken to exclude fractures in anteroposterior and lateral views.[21] *Biomechanical evaluation may reveal* an excessive range of inversion and an excessive range of forward movement of the talus within the ankle mortise (postitive anterior drawer sign).

It should be noted that lax lateral ligaments following an ankle inversion sprain may allow for excessive anterior talar translation, thus facilitating the posterior tibial margin to rest on the calcaneus.[17] Continued posterior impingement may lead to osteoarthritis of the posterior subtalar joint, heterotrophic bone formation near the posterior talar tubercle, and flexor hallucis longus tendinitis.[17] It is important to strengthen the supporting soft tissue musculature to stabilize the ankle mortise, especially the peroneals following an inversion sprain.[13]

Posterior Impingement Syndrome

This syndrome is more common in dancers because of the frequency with which they stand either on pointe or demipointe. The pain is felt at the back of the ankle when the toe is pointed and is due to the presence of a bony prominence behind the ankle that compresses the soft tissues. The posterior impingement syndrome most commonly develops in ballet dancers who have either an os trigonum or Steida's process.[17] The os trigonum can be present congenitally or be the result of repeated talar impingement against the posterior tibia or an acute fracture of the posterior talar tubercle during forced plantar flexion. The pain that results is from crowding of the soft tissue, and an enlarged posterior tubercle can cause just as much pain as an os trigonum. Diagnosis with a plain radiograph is not particularly helpful, but a nuclear bone scan usually shows an area of increased uptake just behind the talus.[17] *Biomechanical evaluation may reveal* tenderness behind the ankle joint and pain with forcible passive plantar flexion of the dancer's foot (this would not cause any pain in dancers with Achilles problems).

Achilles Tendinitis

The Achilles tendon is particularly vulnerable to injury as a result of the frequent and excessive stress placed on it. Achilles tendinitis is a frequent lesion in ballet dancers, appearing in 30.9% of dancers.[21] It is caused by repetitive microtrauma and overuse. Much of the time, the dancer is in the position of demipointe (weight bearing on the metatarsal heads), full point (entire foot at 180 degrees with the tibia), and plié (end-range dorsiflexion of the ankle). When on pointe or demipointe, the gastrocnemius and soleus are in full forceful contraction; during plié, the Achilles tendon is forcefully stretched as in a landing from a jump. Other factors that, when seen in the dancer, may facilitate Achilles tendinitis include tight Achilles tendon[4, 13, 17, 21]; reduced shock absorbency of the dance surface[4, 13, 17]; repetitive jumps[17]; genu recurvatum causing the dancer's weight to fall behind the heel and calf muscles, which thus have to work harder to keep the dancer balanced[13]; pronated feet[4, 17]; and valgus rearfoot.[4] One additional cause of this injury is that some female dancers tie their ankle ribbons of their point shoes too tightly so that the knot of the ribbon presses directly over the Achilles tendon.[13, 21]

The dancer usually complains of pain over the Achilles tendon located at the middle of the tendon or at the musculotendinous junction and sometimes is aware of a grating sensation in it as well. *Biomechanical evaluation may reveal* some thickening and irregularity of the tissues surrounding the tendon, and there may be crepitus with movement. Sometimes a nodule can be felt moving with the tendon. Forceful passive plantar flexion of the dancer's foot is painless, but full dorsiflexion may be restricted by a tight heel cord (be sure to test muscle length of both the gastrocnemius and the soleus because tightness in either muscle can alter proper dorsiflexion range while dancing).

Flexor Hallucis Longus Tendinitis

As already explained, forcing of the turnout and repetitive positions of full plantar flexion and dorsiflexion predispose the flexor hallucis longus tendon to tendinitis. In full plantar flexion (pointe), the tendon is compressed in its groove inside a fibrous sheath over the posterior talar tubercle. In dorsiflexion, the tendon is stretched between the posterior talar tubercle and sustentaculum tali. Repetition of these movements can lead to inflammation.[13, 17] The flexor hallucis longus is the last tendon to activate with take-off and the first to take shock when the dancer lands; it is thus subject to a large eccentric load on landing.[13] Repeated stress and inflammation of the flexor hallucis longus tendon can lead to a partial rupture and fusiform thickening, thus impairing its passage through the fibro-osseous canal.[13, 17] This causes a triggering phenomenon of the hallux, often referred to as *trigger toe*.[17, 25]

Trigger Toe

Trigger toe is characterized by weakness and pain on rising and snapping of the hallux at the ankle when returning from demipointe to the floor at the inferomedial ankle, inferior to the sustentaculum tali. If the dancer plantar flexed (pointes) the ankle and moves the big toe, pain is reproduced if there are flexor hallucis longus tendon problems.[13, 21, 25] The dancer may complain of pain with either plié or rising. Another complaint may be the big toe locking during demipointe work with the dancer unable to release the toe when going into plié. Alternatively, when the ankle is in full plantar flexion, the toe may lock with fully pointed hallux, and there is difficulty with dorsiflexion.[13] *Biomechanical evaluation may reveal* some localized tenderness behind the medial malleolus along the line of the flexor hallucis longus as far as the medial longitudinal arch; clicking or triggering when the big toe is moved; and that with the ankle immobilized, movement of the big toe can produce a palpable swelling that moves with the flexor hallucis longus tendon behind the medial malleolus.

EVALUATION OF THE FOOT

Foot problems make up 13% to 15% of ballet injuries.[17] Performing dance causes major stresses to the feet of the dancer. Joint disease of the midfoot and first metatarsophalangeal joint in dancers is well substantiated and often a significant problem in the dancer's career.[22] A variety of foot injuries have been described, including stress fractures, subluxations, sesmoiditis, hallux disorder, and plantar fasciitis. As previously described, turnout positions, poor or no footwear, hard dance surfaces, long hours of practice, and extreme range of motion all predispose dancers' feet to acute and overuse injuries. Although normal range of extension at the first metatarsophalangeal joint is about 60 degrees, classical dancers routinely need 80 to 100 degrees of extension to permit full rise onto demipointe.[13] If this range of motion is not available, dancers shift their body weight laterally onto the third, fourth, and fifth metartarsals (supination) to compensate. This position is referred to as "sickling in." The position of sickling overstresses the lateral foot structures and compresses the medial structures and can predispose dancers to inversion ankle sprains and lateral foot sprains as well as altering the biomechanical chain from the foot upward.

Cuboid Subluxation

Cuboid subluxation is a common but poorly recognized condition. Marshall and Hamilton[15] studied cuboid subluxation in ballet dancers and reported its incidence to be 17% of foot and ankle injuries.[17] Manual reduction of the cuboid usually yields excellent, often dramatic results in the management of this commonly overlooked affliction. Marshall and Hamilton indicated that it is more common in female dancers as part of an overuse syndrome. Repetitive dorsiflexion and plantar flexion movements may gradually decrease the stability of the tarsometatarsal joints and midtarsal joints.[15, 17] These repetitive forces and reduced joint stability predispose female dancers to cuboid subluxations. Generally, male dancers develop acute subluxation as they land with pronated feet.[15, 17] Cuboid subluxation can also be the sequela of a traumatic sprain of the lateral foot. The subluxation occurs secondary to acute sprains and must be managed carefully to prevent a chronic condition from developing. The peroneus longus may also play a role in some cases.

It becomes tight after a cuboid subluxation and should be relaxed with deep massage of the muscle belly before attempting reduction.[13, 15] Abduction of the forefoot at the midtarsal joints predisposed an individual to plantar cuboid subluxations.[15] The abducted position of the foot must be corrected or diminished to facilitate and maintain reduction of the cuboid. The tendency for dancers to seek the valgus position of the forefoot when on demipointe may also predispose them to subluxations.[13, 15]

A dancer with cuboid subluxation complains of lateral midfoot pain and an inability to "work through the foot" while moving from flat foot to demipointe or full pointe. Jumping is not possible secondary to localized, sharp pain. In addition, pressing on the plantar surface of the cuboid in a dorsal direction produces pain. Frequently, there is a shallow depression on the dorsal surface on the foot and a fullness on the plantar aspect of the cuboid. Radiograph or computed tomography scan is difficult because of the normal variations found in the relationship between the cuboid and its surrounding structures.[15, 17] The diagnosis is primarily subjective and must be made on the basis of the patient's history and physical findings. *Biomechanical evaluation may reveal* painful dorsal glide of the cuboid, markedly reduced or absent cuboid dorsal/plantar joint play as compared to the uninvolved foot, subtle forefoot valgus, peroneus longus spasm in the muscle belly, and the dancer's inability to rise from flat foot to demipointe.

Stress Fractures

Stress fractures are relatively common in dancers.[9, 13, 17, 21] They most commonly occur at the base of the second metatarsal because the whole body weight often rests on this region when in demipointe.[9, 13, 17, 21] In addition, a dancer may not be working with true vertical foot and ankle alignment, transferring more weight to this region. For this reason, most dancer's feet show marked hypertrophy of the second metatarsal, and it is important that this is not confused with a stress fracture. The compressive forces to the second metatarsal are increased with a Morton's foot. The peroneus longus and tibialis posterior, which are important muscles in maintaining the "on point" position, commonly have an attachment to the base of the second metatarsal, thus offering traction specifically to the fracture segment.[9] Other common sites at which stress fractures are seen are the medial sesamoid if the dancer "rolls in on the foot," the third metatarsal shaft, the navicular, the sustentaculum tali, and the distal fibula.[9, 13, 17, 21, 25]

Dancers typically complain of a gradual onset of soreness at the base of the second metatarsal. Investigation requires bone scan, computed tomography, or magnetic resonance imaging because the injury is not evident early on an x-ray. *Biomechanical evaluation may reveal* pain with passive joint mobilization at the base of the second metatarsal, a Morton's foot with a short first metatarsal shaft, and point tenderness at the base of the second metatarsal shaft.

Hallux Valgus

When a dancer stands "on point," she is taking most of her body weight on the first and second ray. These toes are supported, however, by a tight toe cap of the point shoe and by the neighboring toes. Quirk[21] demonstrates that a normal foot is not likely to develop hallux valgus solely as a result of ballet. Dancers who have a natural tendency toward hallux valgus, however, seem to deteriorate more rapidly than usual as a result of dancing on point. A common cause of acquired hallux valgus is excessive rearfoot varus leading to excessive subtalar pronation and subsequent abduction force on the first metatarsophalangeal joint.[13] Excessive rearfoot movement can be modified with the use of rigid orthoses in street shoes; lodi taping may be necessary while dancing without street shoes. Although excessive rearfoot movement can cause hallux valgus, an excessively stiff rearfoot can also cause similar problems. A stiff rearfoot may not allow calcaneal eversion and subtalar joint pronation and thus causes compensatory first ray plantar flexion, increased midtarsal pronation, and subsequent hallux valgus (Fig. 4).[13] *Biomechanical evaluation may reveal* valgus positioning of the first ray, excessive rearfoot varus as tested in subtalar neutral, or diminished rearfoot inversion/eversion as tested in subtalar neutral.

Plantar Fasciitis

Dancers are also prone to developing plantar fasciitis.[25] All the factors mentioned earlier that can contribute to excessive pronation may play a role in this syndrome. Dancers complain of pain along the plantar fascia often with point tenderness at the insertion on the calcaneus. When the plantar fascia is rendered taut with dorsiflexion of all the metatarsophalangeal joints, the metatarsal heads are depressed, thus assisting in elevation of the medial longitudinal arch (windlass effect).[17] Continued demipointe and "rolling in of the foot" place excessive stress on the plantar fascia. Also often involved is a tight Achilles tendon and soleus muscle limiting dorsiflexion and resulting in early pronation in the gait cycle. *Biomechanical evaluation may reveal* pain with passive extension of the metatarsophalangeal joints, point tenderness at the plantar fascia insertion on the calcaneus, and tight posterior calf musculature. It should also be noted that a change in footwear or increase in rehearsal schedule may trigger the onset of plantar fasciitis.[25]

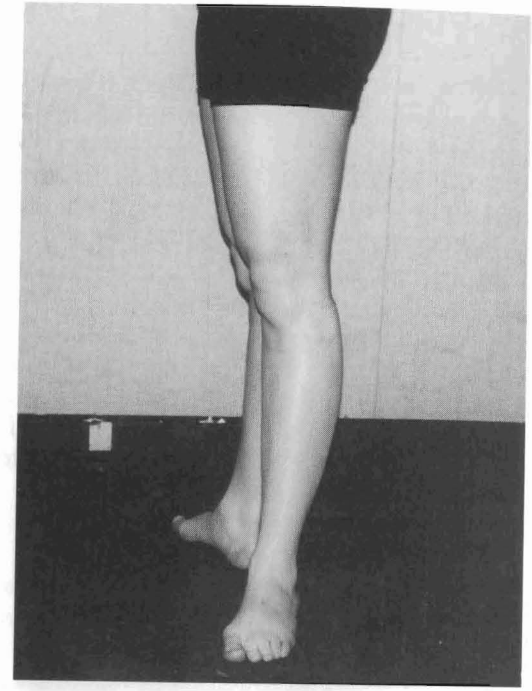

Figure 4 Hallux valgus with pronation from forced turnout.

EVALUATION OF THE LUMBAR SPINE

Spinal injuries are reported to occur in ballet dancer 10% to 17% of the time, with the lumbosacral region being involved in 69% of spinal injuries.[17] The hyperlordotic posture predisposes dancers to injury.[9, 13, 16, 17, 25, 30] This hyperlordotic posture may be due to anatomic malalignment and muscle-tendon imbalance. Weak abdominal muscles and tight thoracolumbar fascia contribute to hyperlordosis. This is most commonly seen in young, inexperienced dancers. Attempting to increase turnout at the hip by swaying the back is another common cause of this posture (Fig. 5). Flexing at the hips allows relaxation of the anterior iliofemoral ligament, permitting maximal external rotation. To remain vertical, however, it becomes necessary to hyperextend at the back resulting in a hyperlordotic posture.[2] Chronic maintenance of this posture produces or exacerbates tightness of the hip flexors, particularly the psoas and rectus femoris.[2] Extreme lumbar extension is necessary in dance in movements such as the *arabesque,* when both maximal hip external rotation and lumbar extension are necessary. If external rotation at the hip is lacking, the dancer may compensate by increasing extension of the lumbar spine. Sometimes, dancers correct excessive lumbar lordosis and strive for and achieve a *flat back,* which contributes

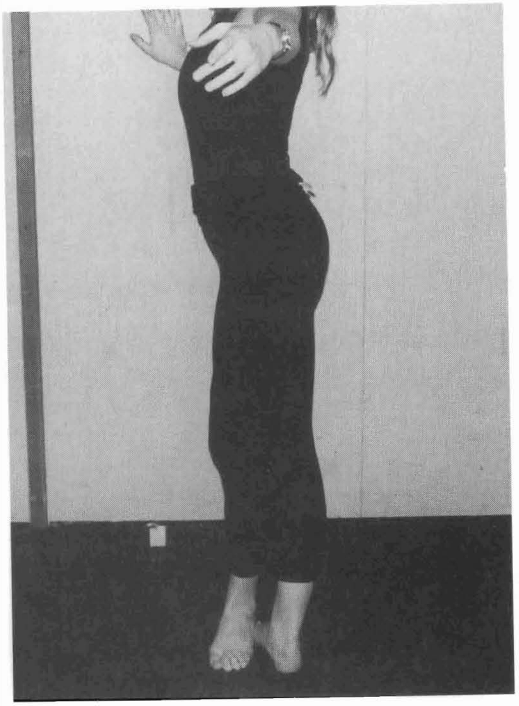

Figure 5 A dancer's attempt to increase turnout at the hips resulting in hyperlordotic posture.

to decreased shock attenuation and thus may contribute to lumbar disk injuries.[13] Floor hardness is also thought to contribute to back injuries. All of these elements result in excessive torsional and compressive stresses to the lumbar spine and place dancers at high risk for acute and overuse injuries of the back.

Spondylolysis and Spondylolisthesis

Spondylolysis of the lumbar spine is three times more common among adolescent female dancers than in the general population.[17] Spondylolysis occurs more frequently in females because females tend to start their training much earlier than males, before the union of the pars interarticularis. The cause of this increased incidence is most probably the repetitive flexion and extension of the spine and a resultant stress fracture of the pars interarticularis of the lumbar spine.[13, 16, 17] The history of back pain is imporant. Pain that was first noted with hyperextension, particularly while standing on one foot as in *arabesque,* is often a predisposing symptom of spondylolysis. Plain x-rays may demonstrate the fracture but must always include oblique views.[13, 16, 30]

The presence of a pars defect, or even a grade I spondylolisthesis (i.e., the vertebra has slipped 25% over the body of the vertebra underlying it), does not mean that a dancer's career is over.[13] Onset of back pain may be a result of an injury superimposed on an old spondylolysis. Bachrach[2] asserts that spondylolisthesis may occur as a progression of bilateral spondylolysis augmented by the pull of the psoas on the vertebral bodies resulting in anterior slippage of the body of L5 on the sacrum. Frequently the avoidance of painful technique and jumping plus strengthening are successful in eliminating pain and allowing return to full dance activities.[13, 16, 30] Biceps femoris, hip flexor, and rectus femoris stretching and abdominal, trunk, and multifidus strengthening are essential. *Biomechanical evaluation may reveal* limitation of motion of the lumbar spine in flexion and pain with hyperextension, pain elicited in extension on one leg associated with a pars fracture on that side, and relative tightness of the hamstrings.

Sacroiliac Dysfunction

Because of the nature of turnout in the dancer, the pelvis is stressed. Although there is no visible motion of the sacroiliac joints, some motion does occur.[25] Dance injuries are seldom caused by one single trauma or physical factor; rather they are usually the result of faulty techniques caused by maladaptive movement patterns. Bachrach[2] describes the psoas insufficiency syndrome in ballet dancers. A tight psoas restricts weight-bearing external rotation (turnout) particularly at end range, which tends to increase hyperlordosis. Also a tight and weakened psoas causes a dancer to present in standing with slightly flexed hips and an increased lumbar lordosis resulting in an anterior displacement of the center of gravity at the lumbosacral level.[2, 17] Unilateral or predominately one-sided psoas shortening results in relative downward and anterior deviation of the innominate on that side. This results in sacroiliac joint dysfunction and loads the iliotibial band, particularly the contralateral, the gluteus maximus, and the hamstrings and tightens the piriformis.[2, 17] As stated previously in evaluation of the hip and knee, dancers are already prone to a tight iliotibial band as well as restricted external rotators. This biomechanical presentation often leads to significant pain and dysfunction at the sacroiliac joint and lower lumbar vertebrae.

Dancers often complain of pain with extension of the lumbar spine and a catch when returning to neutral from flexion. *Biomechanical evaluation may reveal* painful motor points in the belly of the psoas, weakness and tightness of the iliopsoas as tested in the Thomas position, tightness of the iliotibial band with a positive Ober test (often on the contralateral side), tightness of piriformis with restrictions of combined external rotation, flexion and adduction at the hip, observation of uneven landmarks of the anterior and posterior-superior iliac spines, functional lumbar scoliosis convex to the side of predominant psoas contracture, positive forward flexion test (thumbs at the posterior superior iliac spine [PSIS] glide unevenly in forward bending), leg length reversal in a supine-to-sit test, a positive Piedallu's sign, and a positive Gaenslen's test.

SUMMARY

The information presented in this article is designed to provide a knowledge base that practitioners can use to assist in the management of dancers. Understanding the anatomic areas of involvement and their common pathologies, the practitioner can begin to formulate a logical approach to the assessment, treatment, and prevention of dance injuries. Dancers suffer injuries that have a multifactorial origin. It is the rare occasion when one particular factor accounts for one particular injury. When working with dancers, the practitioner must be aware of evaluating the dancer as a whole, seeing not only the presenting injury, but also the complex pattern of biomechanical relationships each dancer possesses.

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