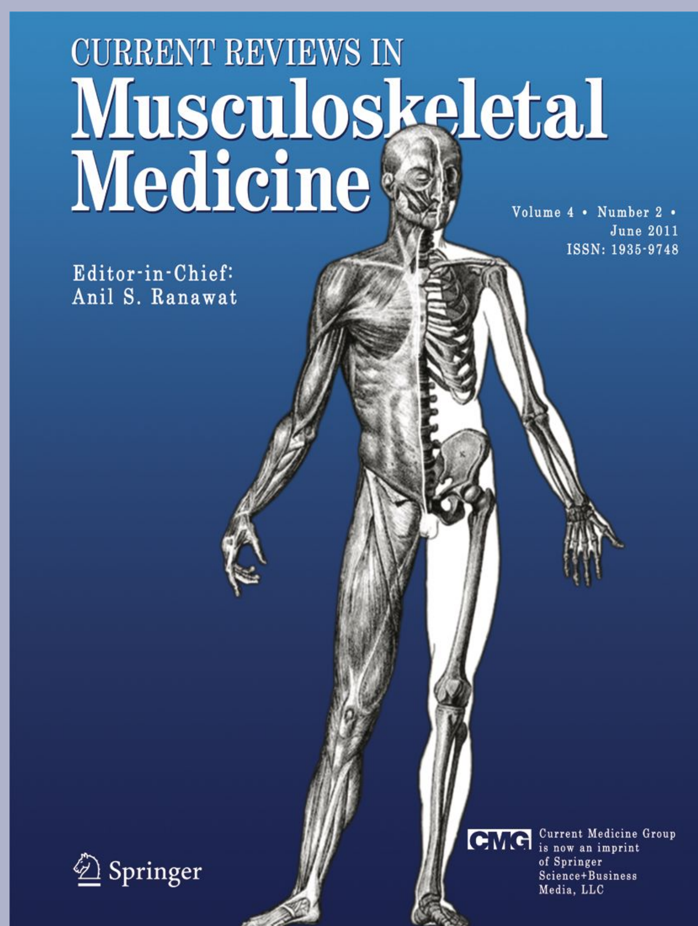
Hip dysplasia and the performing arts: is there a correlation?

Robert Turner, Eilish O'Sullivan & Jaime Edelstein

Current Reviews in Musculoskeletal Medicine

ISSN 1935-973X

Curr Rev Musculoskelet Med
DOI 10.1007/s12178-011-9104-9



Springer

Curr Rev Musculoskelet Med
DOI 10.1007/s12178-011-9104-9

Hip dysplasia and the performing arts: is there a correlation?

Robert Turner · Eilish O'Sullivan · Jaime Edelstein

Abstract Dancers frequently present with hip pain. The etiology of this pathology has not been clearly identified from an anatomical perspective. Structural variations including hip dysplasia and dynamic variables from the foot to the pelvis will be discussed. Understanding the etiology as a structural entity, neuromuscular entity or a combination of the two, allows for a successful rehabilitative process and a successful return to dance. This article describes the possible correlation between hip dysplasia and hip pain in the dancer, the relationship of dance postures to the kinematic chain and outlines possible treatment strategies for management.

Keywords Dancers · Dysplasia · Femoroacetabular impingement · Joint laxity

Introduction

Due to the extreme ranges of motion required for many of the performing arts including Broadway, ballet and modern dance, hip pain and injury is a leading cause of lost work and performance time. Accurate evaluation and diagnostic skills are essential for the development of a comprehensive treatment plan aimed at correcting imbalances in strength, flexibility and neuro-motor sequencing. Screening tools are helpful in identifying performers at risk, however currently an accurate and reliable tool has not been validated [1]. Evaluating the biomechanics of the kinematic chain whether open or closed, is paramount in this population as there are significant demands placed on the standing leg and the gesturing leg at or near the end ranges of available movement. Technique, sequencing, and alignment issues specific to the individual art form must be critically analyzed and corrected to enhance proper joint mechanics and maximize function.

R. Turner (✉) · E. O'Sullivan · J. Edelstein
Hospital for Special Surgery,
525 East 71st Street,
New York, NY 10021, USA
e-mail: turnerr@hss.edu

E. O'Sullivan
e-mail: osullivane@hss.edu

J. Edelstein
e-mail: edelsteinj@hss.edu

Hip dysplasia and pathomechanics

Dysplasia of the hip refers to a wide variety of pathologies which are either present congenitally or as the child grows. By definition, the bones of the hip are not aligned properly, most often resulting in improper orientation of the acetabulum to the femoral head and reduction of contact area between the two surfaces. This structural imbalance has been proposed to be a common cause of labral injury and early onset of hip osteoarthritis [2]. There is a genetic link to the incidence of hip dysplasia [3]. The occurrence of dysplasia has been documented to be 1.4 incidences per 1000 births [4]. The risk of dysplasia is 12% if one of the parents had dysplasia, and 6% if a sibling is diagnosed with dysplasia. Other risk factors include incidence of lower limb deformity, torticollis, metatarsus adductus and extreme ligamentous laxity [4, 5]. The decreased concentration of the pregnancy hormone relaxin has also been implicated with sonographic evidence of hip instability [6]. Hip dysplasia has proven to be more prevalent in females than males and although it may present in both hips, there is an 80% chance it will present in the left hip versus the right [4,

Published online: 05 January 2012

7]. Furthermore, in correlating this to the dance population, female dancers tend to stress the hip joints more than males because the height of the gesturing leg is expected to be higher, and is used as a lever during lifts.

Acetabular dysplasia describes an acetabulum which forms too shallow or is deformed. It has commonly been thought that hip dysplasia is associated with an increase in acetabular anteversion, however it has been demonstrated that this is not the case. Tonnis found that decreased acetabular anteversion (less than 10°; retroversion) was found in 29% of the dysplastic hips he examined, and decreased femoral anteversion (less than 10°; retroversion) in 59% of the dysplastic hips he examined [8]. Femoral variations may also create improper joint alignment. This includes coxa vara, whereby the femoral neck to shaft angle is too narrow measuring less than 120° or coxa valga, whereby the femoral neck to shaft angle may develop too wide, measuring greater than 135° [9]. Radiographically, acetabular dysplasia is defined by the center edge angle, first described by Wiberg, measuring less than 25°, the anterior center edge angle of Lequesne and de Seze of less than 20°, and an acetabular roof obliquity of greater than 10° [10, 11, 12•].

Genda et al. [13] used three dimensional discrete element analysis (DEA) to assess the geometry and contact pressure in hips during simulated single-leg stance. It was determined that a loss of lateral and anterior coverage of the femoral head by the acetabulum increases contact pressure and increases pressure on the anterolateral edge of the acetabulum. This study additionally found that when the center edge angle is small or negative, as in dysplastic hips, the abductor force increased and direction of force changed [13].

A recent study examined the clinical presentation of fifty-seven skeletally mature subjects with hip dysplasia [12•]. Ninety-seven percent of subjects reported insidious onset of their symptoms. In 72%, pain was localized to the groin and in 66% the pain was localized to the lateral hip region. Less common was pain at the anterior thigh (29%) and the buttock region (18%). 80% of subjects reported mechanical symptoms including catching, clicking, popping or locking and their symptoms otherwise ranged from dull in 78% to sharp in 77%. Most notable was the mean time from onset of symptoms until a diagnosis of acetabular dysplasia was made, which ranged from five months to twenty-nine years and averaged 61.5 months. This clearly indicates the paucity of knowledge in the recognition of signs and symptoms of hip dysplasia.

The labrum is a triangularly shaped fibrocartilaginous ring around the edge of the acetabulum. The labrum is made of Type I collagen fibers oriented circumferentially around the rim of the acetabulum [14]. Prior research has elucidated the role of the labrum in protecting the cartilage of the joint by limiting contact pressure, assisting in joint stability and protecting the joint cartilage due to its suction seal properties [15, 16]. In a recent study by Henak et al. [17], the role of the labrum was compared in dysplastic and non-dysplastic hips using volumetric computerized tomography (CT) data during a series of functional tasks including force at heel strike and mid-stance in walking, ascending and descending stairs. The results of the study demonstrated that the labrum in the normal model supported 1–2% of the total load across the hip joint; however in the dysplastic model the labrum supported 4–11% of the load [17]. Contact stress area on the cartilage of the joint did not change with or without the labrum. Regardless of the integrity of the labrum, the contract stress area in the dysplastic hip was smaller and more focal than in the normal hip. Overall, this study indicates that the labrum functions to stabilize the joint versus reduce cartilage contact stresses during activities of daily living [17].

The performing arts profession, particularly ballet, requires extreme ranges of hip motion. Kicks (grand battement) and jumps often require extremes of abduction, hyperextension and external rotation. Turnout refers to a position in ballet in which the feet are rotated at 180° from each other requiring extreme ranges of hip external range of motion [18]. The ability to achieve full turnout is based on structural anatomy, muscle strength of the hip rotators and inert tissue extensibility. Research demonstrates a greater amount of hip external rotation in dancers (84°) versus non-dancers (63°), as well as greater hip flexion (167° versus 147°) and abduction (55° versus 43°). However, dancers had significantly less internal rotation (49° versus 56°) and adduction (−2.3° versus 4.0°) as compared to controls [19]. Khan found similar measures and demonstrated a significant difference in overall range of motion (IR+ER) in female dancers versus non-dancers [20]. This was further explored in 11–14 year olds. Six or more hours of dance training per week were found to significantly decrease femoral torsion, which may lead to decreased congruence of the hip joint, and an increased incidence of labral tears [21].

Hip injuries have been recorded to comprise anywhere from 7% to 50% of injuries in dancers [22]. Retired ballet dancers have been noted to demonstrate a 2.9 greater odds ratio of hip pain than non-dancers [23]. Anderson [24] had proposed that microsubluxation of the hip and acetabular dysplasia were the cause of labral microtrauma. Teitz [25] supported this finding by describing microtrauma to the labrum associated with extreme ranges of external rotation. Capsular microtrauma and ligamentum teres injuries may be caused by repeated external rotation and axial loading, creating microinstability in the hip joint [26]. Bauman et al. [27] theorized that dancers may have dysplastic acetabulae, allowing for the great ranges of motion required. There is only one study known to correlate hip bony morphology and dancers [28••]. Forty-one hips of professional dancers undergoing hip arthroscopy by one physician were examined. Radiographic findings in the dancers were as follows: hip dysplasia (55%), CAM impingement (25%) and normal bony structure (22%). These findings were supported by intra-operative visualization. Ten patients failed operative treatment and were not able to return to professional dance. Most of them had advanced osteoarthritis and seven of the ten did have acetabular dysplasia.

Kinematic implications of the dysplastic hip

Beginning with the contact point of the foot to the floor, proper foot and ankle mechanics may be the origin of alignment dysfunctions which transfer through the knee and hip to the spine. Structural weakness of the foot will need to be corrected in the dancer's technique training. Footwear issues and the ground reaction forces generated during choreography vary based on shoe type [29]. A common source of injury either to the foot itself or further up the kinetic chain is based on the type of shoe being worn for rehearsal and performance [22].

Supination combined with increased rear foot inversion and forefoot adduction can create the appearance of increased external rotation of the limb similar to an increase in femoral/acetabular retroversion. Hamilton et al. found up to 70% of turnout originated from the hip with the remainder coming from the foot/ankle and knee [30–32]. Femoral neck anteversion angles have not been proven to be associated with increased turnout [33]. However dysplasia and ligamentous laxity have been correlated with turnout. These particular combinations of findings may explain the loss of hip internal rotation and adduction found in many dancers [19].

Foot and ankle biomechanics and altered weight bearing patterns associated with pointe work, soft ballet shoes, working barefoot and various character shoes may have an effect on femoroacetabular alignment. As weight is borne on the tips of the toes through a hardened toe box [29], creating significant stress through the foot, there is an anterior translation of the COG through the hip on the standing leg. The contact point to the floor is reduced as well, causing increased demands on the recruitment patterns of the musculature surrounding the standing hip.

Pliés involve flexing the knees while the hip is in an externally rotated position, which is associated with external tibial rotation and a supinated foot. An excessively pronated foot caused either by poor foot mechanics or a loss of support to the medial longitudinal arch of the foot while landing from a jump, will cause an inward rotation of the hip with the knee dropping more to midline. The resultant torque at the knee will not maintain alignment of the COG through the second metatarsal of the foot, causing injury to the knee, foot or hip. To prevent this, the dancer will maximally recruit the hip external rotators. Trepman [34] examined EMG data during the grand-plié and found that the adductors were the prime movers. The greater the turnout, the more efficiently the adductors are able to contribute. The adductors were found to be most active concentrically in the early rising phase of the grand plie, along with the quadriceps. The majority of the stability through the hips and knees is attributed to the hamstrings, quadriceps and adductors, with the gluteus maximus active in the rising phase [34].

When the external rotators and adductors fail to achieve the desired alignment correction due to an active insufficiency of the foot intrinsics, the gluteus maximus and posterior portion of the gluteus medius will be recruited in an attempt to restore balance by externally rotating the hip further but at the cost of also causing a posterior tilt of the pelvis. Posteriorly tilting the pelvis will alter the femoroacetabular dynamics (FAD), thereby adding additional stress to all hip structures.

Femoracetabular/Acetabulofemoral (FAD/AFD) Dynamics Frequently the dancer is standing on one leg while performing a gesture with the other leg. In order to gain height in the gesturing leg, the pelvis must rotate over the femur on the standing leg. This motion of the pelvis over the femur may be referred to as acetabulofemoral dynamics (AFD) while the motion of the femur moving relative to the acetabulum is femoracetabular dynamics (FAD). Dancers require harmonious, independent motion from both sides of the hip joints simultaneously. Femoroacetabular impingements may occur through typical ballet positions even in a hip with no morphological abnormalities [35•] due to the extreme motion demands for the aesthetics. Concentrating on the standing leg alignment is only a partial solution for this population. The gesturing leg frequently is accelerated to end ranges of movement. As it rises to attain maximum height, the pelvis and acetabulum must rotate over the standing femoral head (AFD), affecting the weight bearing forces on the hip joint.

Proper elevation of the gesturing limb involves a combination of FAD/AFD dynamics as well as pelvic rotation, sacral and spinal motions. As the hip is moved into extension, an anterior rotation of the ipsilateral innominate must take place. As the limits of this motion are reached, the lumbar spine must then extend. Therefore, hyperextension of the right limb for a ponche' arabesque causes an anterior rotation of the right innominate with concomitant lumbar extension, right side-bending and right rotation. The standing leg now has the entire pelvis rotated over it with the acetabulum being the mover and the femur stabilized. A lift or a drag from such a position would increase the susceptibility to injury. While the dancer is being lifted, the femur of the gesturing leg acts as a lever for the lift and will rotate and translate the femoral head anteriorly in the acetabulum. Subluxations and impingements can occur in either hip as the femoral head rotates to end range while bony structures make abnormal contact with the acetabulum, ischial tuberosity, or sub-spine region of the pelvis. Most classical ballet techniques involve the right leg as the predominant gesturing leg, while the left leg is the supporting or standing side, although it has not been proven that there is a correlation between laterality and hip injury [36]. Dance typically involves heavy partnering or moving into or out of the floor, which places additional loading stresses on a more flexed hip, thereby altering the weight-bearing surfaces of the hip joint.

Rehabilitation

Successful rehabilitation of this population commands an understanding of the specific physical demands of dance. Within the dance genre there are multiple choreographic styles that one must be familiar with in order to efficiently rehabilitate the dancer. An intimate understanding of these choreographic demands, the mechanism of injury, appropriate clinical reasoning and examination skills, followed by manual therapy and proper neuro-muscular education are required to return the performing artist to the stage. For the acute hip injury, rest and ice are the first line of injury management. As soon as possible, the performer should be evaluated by a clinician with an understanding of their physical demands while diagnostic imaging may be required to make an accurate diagnosis.

Once cleared for physical therapy, the therapist must understand the underlying pathology. Acute spasms and holding patterns may be effectively treated with manual therapy and modalities, but if done too aggressively may cause an unintended instability of the hip. For example, the iliopsoas is used as a primary mover in hip flexion but in a neutral or extended hip position becomes a dynamic stabilizer [2, 37, 38]. To release and stretch this muscle if it is not short or tight, may have the deleterious effect of aggravating an underlying labral injury or psoas tendonitis, while causing there to be less anterior stability to the hip. Coxa saltans (snapping hip) is a common complaint reported in up to 91% of ballet dancers [39]. External snapping hip is caused by iliotibial band or gluteus maximus snapping over the greater trochanter. Internal snapping in caused by the iliopsoas tendon snapping over the femoral head or iliopectineal eminence [40] and has been proposed to be due to expansion of the hip joint capsule in those with dysplasia [41].

For optimal function to take place, muscular actions must occur at the right time, for the right duration, and in the correct combination. Dysfunction may occur due to decreased or increased muscle length, alterations in timing of muscle contractions, stiffness or neuromuscular substitution patterns [42]. As the result of prolonged groin pain, there may be alterations in motor control. These changes in muscle activation and sequencing must be recognized, and the affected muscles re-educated to correct dysfunctional movement patterns through the hip and pelvis. Common deficiencies observed are in the gluteus maximus, the transversus abdominus (TrA), and the gluteus medius. Substitutions may occur and cause decreased stability through the pelvis with reduced efficiency of movement. Special attention should be paid to the sequence of firing during basic movement patterns before more complex patterns are attempted.

During hip extension, there may be a delay in the contraction of the gluteus maximus following activation of the biceps femoris. This demonstrates a delay in the feed-forward and stabilizing mechanism of the trunk [43, 44]. This delay may be minimized by the increased contraction of the TrA [45]. The timing of the trunk muscles (including TrA and erector spinae), hamstrings and gluteals should be assessed with prone hip extension whereby the TrA and gluteals fire prior to the biceps femoris. During abdominal hollowing, the obliques may activate instead of the TrA, which may lead to decrease lumbopelvic stability [46]. Delayed firing of the TrA has also been correlated with the incidence of prolonged low back pain [47], which often occurs in conjunction with hip joint pathology. This may be assessed through abdominal setting or lower abdominal strength testing with the Sahrmann series [48].

Hip abduction may occur through substitution of the quadratus lumborum if there is not adequate stability through the lumbar spine, as achieved through contraction of the TrA. Cynn et al. [49] found that there is a significant increase in the activity of gluteus medius and internal oblique with lumbar stabilization, which is accompanied by a significant decrease in activity of the quadratus lumborum. Stability through the pelvis may be assessed through the Active Straight Leg Raise (ASLR) [50]. The ASLR examines the contribution of the multifidi and TrA to the force closure of the pelvis during lower extremity movement [51]. The relationship between joint hypermobility and injury in dancers was recently examined by Roussel et al. [52]. They found that joint hypermobility (as measured by the Beighton scale) did not predict injuries in dancers, whereas the Knee Lift Abdominal Test [48] and Standing Bow [53] did correlate with injury. Hyperlordotic posture is frequently found in dancers, and may occur due to decreased abdominal control in resisting anterior pelvic tilt during hip extension [52] or when forcing turn-out.

In those with dysplasia, the function of the hip abductor is crucial for providing lateral stability due to the static instability from acetabular under coverage. Grimaldi [54] examined assessment practices for exploring the lateral stability of the hip and pelvis and described ideal pelvic-femoral alignment as that where energy expenditure is most efficient and harmful forces are minimized. A thorough postural assessment is an important component of the examination of the patient with possible lateral hip instability. “Hanging on one hip” [54] or sitting in the hip as dancers refer to it, is where weight is shifted away, and the pelvis drops down contralaterally into relative hip adduction, is commonly adopted by those with decreased lateral hip stability. This increases iliotibial band tension and decreases required muscular stabilization.

Neuromuscular re-education in a non-weight bearing position is most helpful prior to advancing to standing functional exercises. An excellent example of this neuromotor re-education process is utilizing the Pilates Method of exercise [55]. Pilates exercises have been shown to increase TrA thickness and obliquus internus (OI) thickness via real-time ultrasound [56]. Critchely [57] compared Pilates mat exercises to conventional exercise and found that the Pilates group had increased TrA thickness during Pilates exercises (and decreased OI), but there were no changes at rest or during functional postures. Pilates training has been utilized to treat a variety of musculoskeletal pathologies. A six week intervention of Pilates was found to significantly decrease chronic non-specific low back pain in a randomized controlled trial. There were also increases in general health, flexibility, and proprioception [58]. Phrompaet et al. [59] found that a Pilates-based exercise program in healthy volunteers increased lumbopelvic stability in 8 weeks as evidenced by improved performance with the pressure biofeedback unit. Despite the above evidence, Bernardo [60] was unable to find conclusive research for the use of Pilates training in dancers. However, Pilates’ apparatuses provide a unique opportunity for the dancer to rehabilitate injuries in non-weight bearing positions, transition to the supportive resistance of springs, and then gradually transition to weight-bearing exercises.

Once adequate neuromuscular patterns of the core and lower extremity have been adopted, the dancer is then ready to begin weight-bearing strengthening exercises which include standing hip rotation on the rotary discs as well as controlled, low friction standing abduction/adduction and splits performed on the reformer with very low springs to aid in a more intrinsically controlled motion. The lighter the resistance, the more intrinsic control the dancer must exert in order to control the motion. It is only after successful completion of this phase that the dancer is ready to put on their ballet shoes and begin standing barre exercises. The dancer may now integrate firing patterns learned from the previous phases and work against gravity with full body weight. Exercises are progressed similarly to a ballet class. Proper alignment and form must be demonstrated prior to beginning plyometric preparation exercises. It is recommended that plyometrics be initiated when there is adequate lumbopelvic stability with good alignment from the foot to the hip, pelvis and spine.

Conclusion

There is clearly evidence of hip pain and instability in the dance population. There are no current studies in the literature which directly correlate the incidence of dysplastic hips to the overall dance population, however recent research has indirectly created this link. Future prospective studies examining hip dysplasia in dancers may establish normative rates of dysplasia and extreme ranges of motion.

Whether increased hip range of motion requirements are due to dysplasia, hypermobility/laxity or retroversion, neuromotor control and planning strategies are essential components of the art form. Pilates exercises may provide the necessary environment for the dancer to master the intrinsic control necessary to stabilize the hips while allowing freedom for effortless movement as a transition from non-weight bearing table exercises to standing functional dance training with the hip in a fully loaded position. Extreme ranges of motion are required in dance and the forces placed through the hip make rehabilitating this population a challenge. Understanding the mechanics of dance postures, the associated biomechanical and kinetic relationships, and clinical etiology of the injury will allow for a successful rehabilitation process.

Disclosures No potential conflicts of interest relevant to this article were reported.

References

Papers of particular interest, published recently, have been highlighted as:
- • Of importance
- •• Of major importance

1. Gamboa JM, Roberts LA, Maring J, Fergsu A. Injury patterns in elite preprofessional ballet dancers and the utility of screening programs to identify risk characteristics. J Orthop Sport Phys. 2008;38:126–36.
2. Michaeli DA, Murphy SB, Hipp JA. Comparison of predicted and measured contact pressures in normal and dysplastic hips. Med Eng Phys. 1997;19:180–6.

3. Dai J, Dongquan S, Pengsheng Z, et al. Association of a single nucleotide polymorphism in growth differentiate factor 5 with congenital dysplasia of the hip: a case–control study. Arthritis Res Ther. 2008;10:R126.
4. Weinstein S. Natural history of congenital hip dislocation and hip dislocation. Clin Orthop and Rel Res. 1987;225:62–76.
5. Von Heideken J, Green DW, Burke SW, et al. The relationship between developmental dysplasia of the hip and congenital muscular torticollis. J Pediatr Orthop. 2006;26:805–8.
6. Forst J, Forst C, Forst R, Heller KD. Pathogenetic relevance of the pregnancy hormone relaxin to inborn hip instability. Arch Orthop Trauma Surg. 1997;116:209–12.
7. Bache CE, Clegg J, Herron M. Risk factors for developmental dysplasia of the hip: ultrasonographic findings in the Neonatal period. J Pediatr Orth B. 2002;11:212–8.
8. Tonnis D, Heinecke A. Current concepts review—acetabular and femoral anteversion: relationship with osteoarthritis of the hip. J Bone Joint Surg Am. 1999;81:1747–70.
9. Clohisy JC, Nunley RM, Carlisle JC, Schoenecker PL. Incidence and characteristics of femoral deformities in the dysplastic hip. Clin Orthop Relat Res. 2009;467:128–34.
10. Wiberg G. Studies of acetabular and congenital subluxation of the hip joint with special reference to complications of osteoarthritis. Acta Chir Scand. 1939;83(Suppl):58.
11. Murphy SB, Ganz R, Muller ME. The prognosis in untreated dysplasia of the hip. A study of radiographic factors that predict the outcome. JBJS Am. 1995;77:985–9.
12. • Nunley RM, Prather H, Hunt D et al. Clinical Presentation of symptomatic acetabular dysplasia in skeletally mature patients. JBJS Am 2011;93(Suppl):17–21. *57 patients with hip dysplasia were followed prospectively with a wide variety of presentations in terms of pain and function. Patients saw an average of 3.3 healthcare practitioners before receiving a definitive diagnosis. There was a significant improvement in symptoms with periacetabular osteotomy.*
13. Genda E, Iwasaki N, Bruce GL, et al. Normal hip joint contact pressure distribution in single-leg standing—effect of gender and anatomic parameters. J Biomech. 2001;34:895–905.
14. Petersen W, Petersen F, Tillman B. Structure and vascularization of the acetabular labrum with regard to the pathogenesis and healing of the labral lesions. Arch Orthop Trauma Surg. 2003;123:283–8.
15. Ferguson SJ, Bryant JT, Ganz R, Ito K. An in vitro investigation f the acetabular labral seal in hip joint mechanics. J Biomech. 2003;36:171–8.
16. Ferguson SJ, Bryant JT, Ganz R, Ito K. The influence of the acetabular labrum on the hip joint cartilage consolidation: a poroelastic finite element model. J Biomech. 2000;33:953–60.
17. Henak CR, Ellis BJ, Harris MD, et al. Role of the acetabular labrum in load support across the hip joint. J Biomech. 2011;44:2201–6.
18. Khan K, Brown J, Way S, et al. Overuse injuries in classical ballet. Sports Med. 1995;19:341–57.
19. Reid DC, Burnham RS, Saboe LA, Kushner SF. Lower extremity flexibility patterns in classical ballet dancers and their correlation to lateral hip and knee injuries. Am J Sport Med. 1987;15:347–52.
20. Khan K, Roberts P, Nattrass C, et al. Hip and ankle range of motion in elite classical ballet dancers and controls. Clin J Sport Med. 1997;7:174–9.
21. Hamilton D, Aronsen P, Loken JH, et al. Dance training intensity at 11–14 years is associated with femoral tosion in classical ballet dancers. Br J Sports Med. 2006;40:299–303.
22. Bronner S, Brownstein B. Profile of dance injuries in a broadway show: a discussion of issues in dance medicine epidemiology. J Orthop Sport Phys. 1997;26:87–94.
23. Ronkko R, Heliovaara M, Malmivaara A, et al. Musculoskeletal pain, disability and quality of life among retired dancers. J Dance Med Sci. 2007;11:105–9.
24. Anderson BD. Cost containment of a professional ballet company through in-house physical therapy. J Shoulder Elbow Surgys Ther. 2003;31:365–73.
25. Teitz C. Hip and knee injuries in dancers. J Dance Med Sci. 2000;4:23–9.
26. Cerezal L, Arnaiz J, Canga A, et al. Emerging topics on the hip: ligamentum teres and hip microinstability. Eur J Radiol 2011; In press.
27. Bauman PA, Singson R, Hamilton WG. Femoral neck anteversion in ballerinas. Clin Orthop Relat Res. 1994;302:57–63.
28. •• Brown HC, Kelly BT, Padgett DE. Hip arthroscopy in the professional dancer. AAOS Annual Meeting. 2011; Podium 642. *40 Dancers status post hip arthroscopy were retrospectively examined with the average length of time to return to work of 7.4 months. Dysplasia was associated with a decreased return to work (63%). Best indicators for optimal outcome were Cam impingement, young age, and minimal chondral damage.*
29. Walter HL, Docherty CL, Schrader J. Ground reaction forces in ballet dancers landing in flat shoes versus pointe shoes. J Dance Med Sci. 2011;15(2):61–4.
30. Hamilton WD, Hamilton LH, et al. A profile of the musculoskeletal characteristics of elite professional ballet dancers. Am J Sports Med. 1992;20:267.
31. Negus V, Hopper D, Briffa NK. Association between turnout and lower extremity injuries in classical ballet dancers. J Orthop Sport Phys. 2005;35:307–18.
32. Gilbert CB, Gross MT, Klug KB. Relationship between hip external rotation and turnout angle for the five classical ballet positions. J Orthop Sports Phys Ther. 1998;27:339–47.
33. Bauman PA, Singson R, Hamilton WG. Femoral neck anteversion in ballerinas. Clin Orthop Relat Res. 1994;302:57–63.
34. Trepman E, Gellman RE, Micheli LJ, De Luca CJ. Electromyographic analysis of grand-plie in ballet and modern dancers. Med Sci Sport Exer. 1998;30:1708–20.
35. • Charbonnier C, Kolo FC, Duthon VB, et al. Assessment of congruence and impingement of the hip joint in professional ballet dancers: a motion capture study. Am J Sport Med 2011;39:557–566. *11 dancers examined with motion capture and optical tracking during dance movements. Femoroacetabular impingement was found to occur in the superior/posterior acetabulum with certain movements, which corresponded to areas of labral damage found. Some dance movements should be practiced with a limited frequency in the symptomatic hip.*
36. Kimmerle M. Lateral bias, functional asymmetry, dance training and dance injuries. J Dance Med Sci. 2010;14(2):58–66.
37. Santaguida PL, McGill SM. The psoas major muscle: a three-dimensional geometric study. J Biomech. 1995;28:339–45.
38. Bogduk N, Pearcy M, Hadfield G. Anatomy and biomechaics of psoas major. Clin Biomech. 1992;7:109–19.
39. Winston P, Awan R, Cassidy JD, Bleakley RK. Clinical examination and ultrasound of self-reported snapping hip syndrome in elite ballet dancers. Am J Sport Med. 2007;35:118–26.
40. Allen WC, Cope R. Coxa saltans: the snapping hip revisited. J Am Acad Orthop Surg. 1995;3:303–8.
41. Bellabarba C, Sheinkop MB, Kuo KN. Idiopathic hip instability: an unrecognized cause of coax saltans in the adult. Clin Orthop Relat Res. 1998;355:261–71.
42. Comerford MJ, Mottram SL. Movement and stability dysfunction—contemporary developments. Manual Ther. 2001;6:15–26.
43. Bullock-Saxton JE, Janda V, Bullock M. The influence of ankle sprain injury on muscle activation during hip extension. Int J Sports Med. 1994;15:330–4.

44. Hodges PW, Richardson CA. Contraction of the abdominal muscles associated with movement of the lower limb. Phys Ther. 1997;77:132–44.
45. Chance-Larsen K, Littlewood C, Garth A. Prone hip extension with lower abdominal hollowing improves the relative timing of gluteus maximus activation in relation to biceps femoris. Manual Ther. 2010;15:61–5.
46. Richardson CA, Jull GA. Muscle control—pain control. What exercises would you prescribe? Manual Ther. 1995;1:2–10.
47. Hodges PW, Richardson CA. Inefficient muscular stabilization of the lumbar spine associated with low back pain: a motor control evaluation of transversus abdominis. Spine. 1996;21:2640–50.
48. Sahrmann S. Diagnosis and treatment of movement impairment syndromes. London: Mosby; 2002.
49. Cynn HS, Oh JS, Kwon OY, Yi CH. Effects of lumbar stabilization using a pressure biofeedback unit on muscle activity and lateral pelvic tilt during hip abduction in sidelying. Arch Phys Med Rehabil. 2006;87:1454–8.
50. Mens JM, Vleeming, Snijders CJ, et al. The active straight leg raising test and mobility of the pelvic joints. Eur Spine J. 1999;8:468–73.
51. Lee D, Lee LJ. Techniques and tools for assessing the lumbopelvic-hip complex. In: Lee D, editor. The pelvic girdle. New York: Elsevier; 173–282.
52. Roussel NA, Nijs J, Mottram S, et al. Altered lumbopelvic movement control but not generalized joint hypermobility is associated with increased injury in dancers: a prospective study. Manual Ther. 2009;14:630–5.
53. Luomajoki H, Kool J, de Bruin E, Airaksinen O. Reliability of movement control tests in the lumbar spine. BMC Musculoskel Dis. 2007;8:90–101.
54. Grimaldi A. Assessing lateral stability of the hip and pelvis. Manual Ther. 2011;16:26–32.
55. Pilates JH, Miller WJ. A Pilates primer—the millennium edition: return to life through contrology and your health. Presentation Dynamics, Inc. 2000.
56. Endleman I, Critchley DJ. Transversus abdominis and obliquus internus activity during pilates exercises: measurement with ultrasound scanning. Arch Phys Med Rehabil. 2008;89:2205–12.
57. Critchley DJ, Pierson Z, Battersby G. Effect of pilates mat exercises and conventional exercise programmes on transversus abdominis and obliquus internus abdominis activity: pilot randomized trial. Manual Ther. 2011;16:183–9.
58. Gladwell V, Head S, Haggar M, Beneke R. Does a program of pilates improve chronic non-specific low back pain? J Sport Rehabil. 2006;15:338–50.
59. Phrompaet S, Paungmali A, Pirunsan U, Sitilertpisan P. Effects of pilates training on lumbo-pelvic stability and flexibility. Asian J Sport Med. 2011;2:16–22.
60. Bernardo LM, Nagle EF. Does pilates training benefit dancers? An appraisal of Pilates research literature. J of Dance Med and Sci. 2006;10:46–50.