Twenty-Year Systematic Review of the Hip Pathology, Risk Factors, Treatment, and Clinical Outcomes in Artistic Athletes—Dancers, Figure Skaters, and Gymnasts

Ioanna Bolia, MD, MSc,* Hajime Utsunomiya, MD, PhD,* Renato Locks, MD,* Karen Briggs, MPH, MBA,* and Marc J. Philippon, MD*†

Abstract

Objective: To identify (1) the predominant level of evidence of the clinical studies regarding the hip pathology, risk factors, treatment, and clinical outcomes in artistic athletes (dancers, figure skaters, and gymnasts) (2) the most commonly reported hip pathology, risk factors, treatments, and clinical outcomes in dancers, figure skaters, and gymnasts. **Methods:** To conduct this systematic review PubMed, EMBASE, and Scopus databases were searched for relevant studies and pertinent data were collected from the eligible articles. Included were studies which reported hip injuries in artistic athletes, the risk factors, treatment, and/or the clinical outcomes. We excluded case reports or irrelevant studies. No meta-analysis was performed because of study heterogeneity. The methodical index for nonrandomized studies (MINORS) criteria were used for quality control. **Main Results:** Thirty-eight studies were included in the analysis. The mean MINORS score was 13.6 ± 4.6 points indicating fair quality of evidence of the included articles. The predominant level of evidence was level IV. Chondrolabral pathology and muscle injuries were the most commonly reported pathologies. We found only 2 risk factor analysis studies; however, many studies reported risk correlation between artistic sports or imaging findings and hip pathology. Treatment strategies were reported in only 7 studies, clinical outcomes are significantly underreported. **Conclusion:** Chondrolabral pathology was the most commonly reported hip pathology in artistic athletes, however, prospective cohort studies are necessary to really understand these injuries and their associated risk factors. The lack of clinical outcomes is significant and future data collection is required to assess the effectiveness of the various treatments.

Key Words: hip labrum, ligamentum teres, ballet, ice skating, gymnastics, muscle

(*Clin J Sport Med* 2018;28:82–90)

INTRODUCTION

The presence of hip pathology in athletes may be the result of an acute injury or an overuse syndrome. Labral tears, acetabular and/or femoral head chondral defects, tearing of the ligamentum teres, or joint instability are common.[1] Avascular necrosis of the femoral head in athletes, although less common, can occur because of prolonged anabolic steroid administration.[2] Diagnosis of hip pathology in athletes can be challenging, partially because of the complex anatomy of the joint which makes it difficult for the patient to localize the pain.[3] Especially for labral tears, a study revealed that the mean time from symptom manifestation to the definitive diagnosis was 21 months, whereas these patients were seen by 3.3 healthcare providers on average before the establishment of this diagnosis which was arthroscopically confirmed.[4] In addition, pathology from the surrounding areas (sacroiliac joint, abdomen, and groin) may manifest with hip pain.[3]

Artistic sports, like dance, figure skating, and gymnastics, may predispose the athletes to hip injuries because of repetitive extreme range of motion in the hip joint during performance. Although these 3 sports share some similar movements (arabesque, attitude etc.) in terms of hip biomechanics, the manifestation of hip pathology is sport-specific; the combination of joint hyperelasticity and acetabular dysplasia (lateral center edge (CE) angle <25 degrees) in dancers is an example.[5,6] During gymnastics, the athlete often lands on his feet after a high-jump movement which further increases the load on the hip joint (hip flexion under stress).[7] Acceleration phase in figure skating requires a "push off" motion of the hip joint (push leg) in abduction and external rotation, similar to the Peewee ice hockey sprint start.[8] The last has been shown be an "at risk" hip maneuver. Based on the above, detailed biomechanical analysis of each sport is necessary to deeply understand the mechanisms that lead to hip injury.

However, it is important for the hip sports health professionals to be provided with appropriate clinical information to be able to develop injury prevention strategies and improve the clinical care of hip injuries in artistic athletes. For the purposes of

Submitted for publication December 30, 2016; accepted March 16, 2017.

*From the *Steadman Philippon Research Institute, Vail, Colorado; and †The Steadman Clinic, Vail, Colorado.*

M. J. Philippon receives research support from National Institute of Health, National Institute of Arthritis and Musculoskeletal ans Skin Diseases, National Institute of Aging, Smith and Nephew Endoscopy, Ossur, Arthrex, Siemens and Royalties from Bledsoe, ConMed Linvatec, DonJoy, SLACK Inc., Elsevier. M. J. Philippon is stockholder of Arthrosurface, MJP Innovations, LLC, MIS, Vail Valley Medical Center-Governing. The remaining authors report no conflicts of interest.

Corresponding Author: Marc J. Philippon, MD, Steadman Philippon Research Institute, The Stedman Clinic, 181 West Meadow Drive, Suite 400, Vail, CO 81657 (karen.briggs@sprivail.org).

http://dx.doi.org/10.1097/JSM.0000000000000440

this study, the term "hip pathology" refers to: intra-articular hip findings (hip joint bones, labrum, cartilage, and capsule) and periarticular hip findings (hamstrings, iliopsoas, groin muscles, and pelvic bone). This study aimed to identify the most commonly reported hip injuries and the associated risk factors in dancers, figure skaters, and gymnasts as well as the current treatment strategies and the clinical outcomes for this pathology. Finally, the study aimed to report the level of evidence of the existing studies on this subject and provide a complete bibliographic overview useful to the healthcare providers.

METHODS

Search and Screening Process

This study was conducted by adhering to the preferred reporting items for systematic reviews and meta-analysis (PRISMA) guidelines. Initially, the inclusion and exclusion criteria were defined by the primary author of this study (I.B.). Next, the criteria were discussed separately with 2 reviewers (H.U., R.L.) until a final agreement was reached. Table 1 provides the inclusion and exclusion criteria. A broad search was performed in 3 databases, (PubMed, EMBASE, and Scopus) using key words and additional constraints based on the available options. PubMed was searched using different key words on the Mesh advanced search tool and additional search constraints were applied to further narrow down the results, a process that yielded 369 studies. EMBASE and Scopus databases were also searched using key terms and subsequent application of search limitations was performed yielding 420 and 544 studies, respectively. Our initial study list counted for a total of 1333 studies. Five hundred twenty-nine studies from this initial list were identified as duplicates and removed. This left us with a total of 662 studies. The titles and abstracts of these 662 studies were reviewed based on the predetermined inclusion and exclusion criteria by 2 reviewers (I.B., H.U.) The studies where disagreement occurred were discussed to decide their final inclusion or not with a third reviewer (K.B.). After this process, a total of 540 studies were excluded leaving 122 studies in our list. Full-text screening of the 122 studies followed and was conducted by 2 reviewers (I.B., R.L.) which excluded 25 studies. Figure 1 shows the PRISMA flow diagram of study selection process.

Collection of Data and Text Report

Data extraction was performed for the quantitative articles by 3 reviewers (I.B., H.U., R.L.) using predetermined tables and a brief "training" to ensure the consistency of the results. We designed 3 different tables to extract the data; hip pathology table, risk factor table, and treatment and clinical outcomes table. Studies that were eligible but not included in the analysis were placed in the qualitative synthesis category of studies which means that they contributed to the text of this systematic review and contained useful information to critically evaluate and discuss our results. On the other hand, quantitative studies were those finally included in our analysis to extract results; they contained numerical data that were reviewed and analyzed.

Quality Assessment of Included Studies

A quality assessment of all the quantitative contributing studies was completed using the methodological index for

TABLE 1. Study Criteria

Inclusion	Exclusion
Prospective and retrospective study design	Level I, II, III, IV, and V biomechanical–biomotional and/or anatomical studies
Level I, II, III, IV, and IV studies reporting hip pathology and/or injury in at least 1 artistic athlete* (dancer, gymnast, and figure skater)	Level I, II, III, IV, and V studies not reporting hip pathology and/or injury in at least 1 artistic athlete* (dancer, gymnast, and figure skater)
Level I, II, III, IV, and IV studies reporting risk factors for hip pathology and/or injury in at least 1 artistic athlete*	Level I, II, III, IV, and V studies not reporting risk factors for hip pathology and/or injury in at least 1 artistic athlete*
Level I, II, III, IV, and IV studies reporting applied treatments and/or clinical outcomes in at least 1 artistic athlete*	Level I, II, III, IV, and V studies not reporting applied treatments and/or clinical outcomes in at least 1 artistic athlete*
Review articles (systematic or not) regarding artistic athletes* referred to hip pathology and/or risk factors and/or treatment and/or clinical outcomes	Review articles (systematic or not) regarding artistic athletes* not referred to hip pathology and/or risk factors and/or treatment and/or clinical outcomes
Study in English including only human subjects	Non-English articles and nonhuman subjects in the study population
Study is published in Pubmed indexed	Studies before 1987 and not published in Pubmed indexed scientific journal
Scientific journal between 1987-2016	Studies including artistic athletes* but as a part of a broader category without specifying their participating sport and the corresponding data
Study population includes artistic athletes* of all ages and all levels	Studies reporting different kind of injuries including hip, though, not reporting the hip specific variables because the latter were included in a broader subcategory of the study population (ex. "lower extremity injuries")
Studies of all levels reporting different injuries including hip and having at least 1 artistic athlete* in their population	Studies with inaccessible full-text (3 reviewers)
Studies with available full text (at least 1 reviewer had easy access)	Subjects with pre-existing hip pathologies contributing to the current hip pathology or hip injuries sustained in activities other than dancing, gymnastics, or figure skating
Subjects that the hip pathology/injury was a result of dancing, gymnastics, and figure skating participation	

** Artistic athlete/sports = dance(er) (all kinds) and/or gymnast(ics) and/or figure skating(er).*

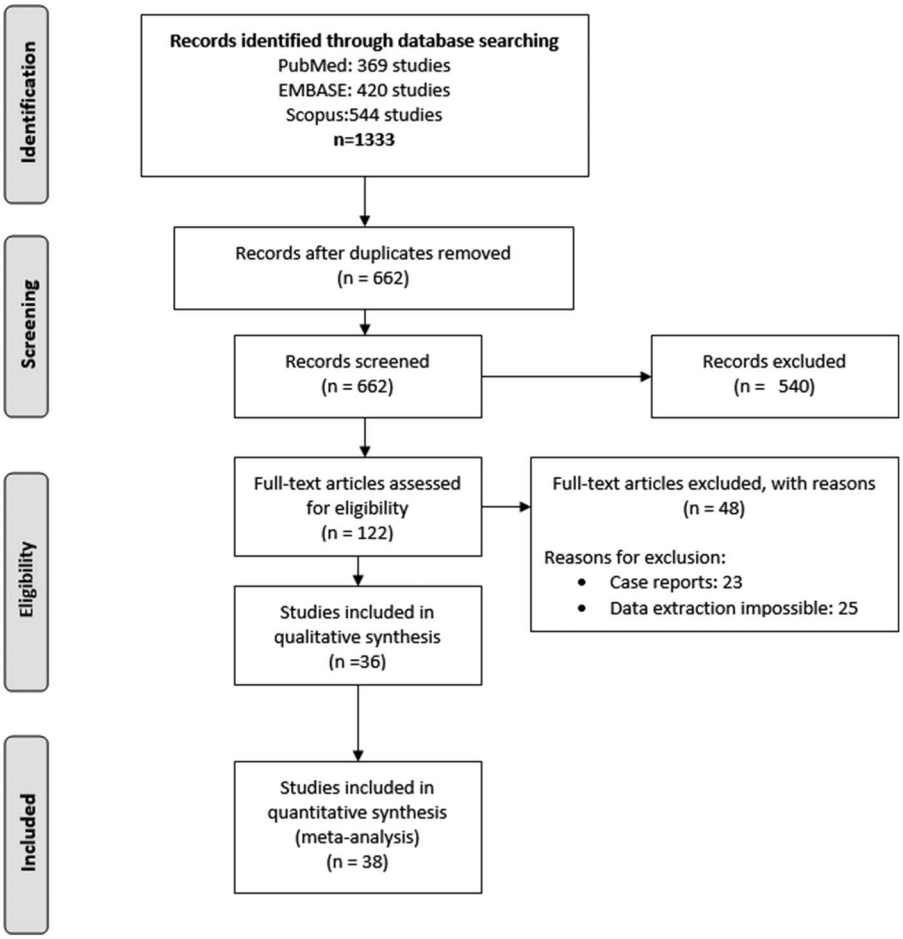

Figure 1. PRISMA flow diagram.

nonrandomized studies (MINORS) criteria.[9] MINORS is a validated scoring tool for nonrandomized studies (eg, case reports, case series, cohort studies, case control studies etc). Each of the 12 items in the MINORS criteria is given a score of 0, 1, or 2—giving a maximum score of 16 for noncomparative studies and a maximum score of 24 for comparative studies. In addition, the number of citations that each article had received on PubMed database, Research Gate network, and the journal of publication partially contributed to that decision. In cases of disagreement, the primary author (I.B.) made the final decision.

RESULTS

Study Characteristics

Seventy-four studies were eligible. However, 38 studies were finally included, reviewed, and analyzed (quantitative studies). The remaining 36 studies were general review articles (Appendix 1 Section 1).

Study Quality

The assessment of the included studies using the MINORS score was completed with 91% agreement between 2 reviewers (R.L., H.U.) who performed a blinded review of the 38 studies. The average MINORS score of the included studies was 13.6 ± 4.6, which indicates a fair quality of evidence of the included articles.

Study Overview and Level of Evidence

The included studies were significantly variable in terms of study population and the method used to report their results (variable definitions). Consequently, no meta-analysis of the abstracted data was possible. Figure 2 provides the overall distribution of the included studies based on the content.

The most included studies were of level IV of evidence (n = 17, 44.7%%). The distribution of the studies based on the level of evidence is shown in Figure 3. We only identified 7 out of 38 (18.4%) studies that used a control group for comparison.

Hip Pathology

The total number of studies reporting hip pathology and including at least one artistic athlete was 38.

To identify the most commonly reported pathology in artistic athletes, we abstracted the data only from studies where the population consisted exclusively of artistic athletes and the prevalence findings were specific for hip pathology (Table 2). However, these studies presented significant heterogeneity regarding the study population characteristics and the definition of actual hip pathology reported, therefore, a meta-analysis was not performed.

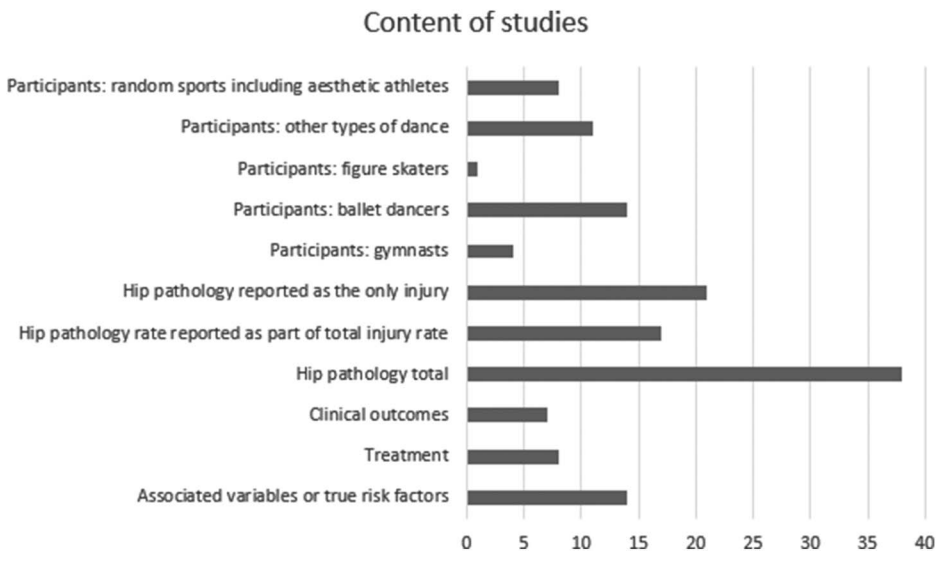

Figure 2. Distribution of the studies based on the content.

Regarding the intra-articular hip injury, chondrolabral pathology was most commonly reported. Some articles concluded that these pathologies are more common in artistic athletes than in the control population,[10,11] however, other studies could not show statistically significant differences.[12,13] Regarding the extra-articular hip injuries, iliopsoas[14–19] pathology, especially the psoas snapping was the most frequently reported injury followed by the hamstrings muscles.[20–23]

Risk Factors

We reviewed 14 articles to identify potential risk factors of hip injury among artistic athletes.[10,12,13,23–33] Only 2 articles were identified as pure risk factor analysis articles relevant to our research question (Table 3). They showed that 2 functional tests ("KLAT" and "Standing bow") has been shown to be predictive of lower extremity injury (including hip) in dancers.[30,33]

Treatment and Clinical Outcomes

Only 7 articles were identified in this category. One of them did not report the clinical outcomes of the treatment applied. We found 7 case series studies, 2 of them reporting arthroscopic surgery for FAI and 1 study the surgical treatment of Legg–Calve–Perthes disease. There were no randomized control trials or comparative case series studies regarding treatment and/or clinical outcomes for hip pathology in artistic athletes. Overall, we observed that surgical treatment is preferred in patients with intra-articular and traumatic pathologies and nonoperative treatment in patients with extra-articular and overuse pathologies.

DISCUSSION

The findings of this systematic review showed significant variability between the existing studies regarding the hip pathology and its clinical approach in dancers, figure skaters, and gymnasts. Based on our study, the most commonly

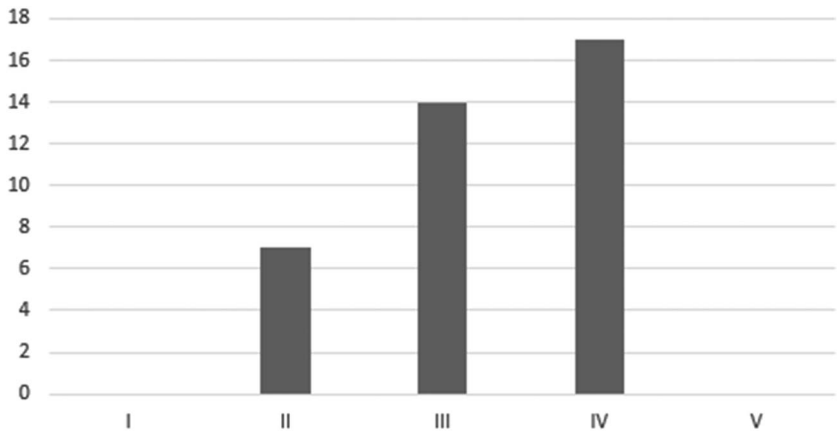

Figure 3. Distribution of clinical studies based on the level of evidence. For studies, the level of evidence was not mentioned on the abstract; the classification was based on: Levels of Evidence For Primary Research Question As Adopted by the North American Spine Society January 2005.[42]

TABLE 2. Studies Reporting Prevalence of Hip Pathology in Artistic Athletes

Reference	Participants	Study Findings	Comments
Mayes et al[13]	49 current and retired professional ballet dancers vs 49 age/sex matched nondancing athletes	No significant difference in the prevalence of hip cartilage defects between the groups ($P = 0.54$)	61% (30/49) of the ballet dancers and 55% (27/49) of the athletes had hip cartilage defects
		No difference between the prevalence of grade 1 and 2 cartilage defects between the 2 groups ($P = 0.83$)	Study using 3T MRI findings
Mayes et al, 2016[12]	49 current and retired professional ballet dancers vs 49 age/sex matched nondancing athletes	No significant difference in the prevalence of hip labral tears between dancers and nondancers ($P = 0.41$)	54% (53/98) of the dancers' hips had labral tear
	N = 196 hips		51% (100/196) of all hips had labral tear
			Study using 3T MRI findings
Mayes et al[10]	49 current and retired professional ballet dancers vs 49 age/sex matched nondancing athletes	Ballet dancers have significantly higher prevalence of ligamentum teres tears compared with nondancing athletes ($P = 0.001$)	The frequency of ligamentum teres tears in ballet dancers was 55% vs 22% in nondancing athletes
			Study using 3T MRI findings
Papavasiliou et al[11]	12 asymptomatic professional gymnasts	Significant difference was found between the diameter of ligamentum teres between gymnasts and nonathletes ($P = 0.05$)	Gymnasts had higher than normal center column diaphysis angle (140 ± 6 degree)
	12 aged matched nonathletes		62,5% (15/24) of gymnasts' hips had ischiofemoral impingement
			16% (4/24) of gymnasts' hips had abnormal signal labrum
Duthon et al[24]	20 professional female ballet dancers vs 14 active age matched females	12/20 dancers reported groin pain only when dancing were all the controls were asymptomatic	Questionnaire MRI based study: MRI was performed in 39 hips of dancers (1 hip excluded because of MRI technical problems) and 28 hips of controls
		Femoral neck-shaft angle was significantly different between dancers and controls ($P = 0.003$)	12/20 dancers reported groin pain only when dancing were all the controls were asymptomatic
		No significant difference was found between the 2 groups in femoral neck anteversion ($P = 0.386$), acetabular depth ($P = 0.065$), acetabular version ($P = 0.172$), and alpha angle (8 positions)	
Van Dijk et al[40]	19 female retired professional ballet dancers (50-70 yr old) vs 19 pair matched controls by age, height, and body weight	No significant difference in joint space between the 2 groups was found (left hip $P = 0.398$, right hip $P = 0.778$)	Range of motion results: Dancers had significantly increases ($P < 0.005$) in flexion (136 vs 123 degrees), external rotation (45 vs 24 degrees) and abduction (40 vs 31 degree) of the hip. The other movements were not significantly different between the 2 groups.
		No significant difference was found between the 2 groups regarding amount of hip arthrosis (Hermodsson classification) (left hip $P = 0.575$, right hip $P = 0.260$)	
Harris et al[26]	47 professional ballet dancers (94 hips), male = 21 female = 26, age: 23.8 ± 5.4 yr	CAM deformity: 15/47 subjects (31.9%), 24/94 hips (25.5%)	Radiography based study: 4 plain radiographs were obtained (standing anteroposterior pelvis, bilateral false profile, and supine Dunn 45 degrees)
		Pincer deformity: 35/47 (74%) subjects had at least 2 radiographic signs	
		Dysplasia or borderline dysplasia: 42/47 (89%) in at least 1 hip	
Gross et al[41]	37 professional ballet dancers; age: 18-33	Dancers with a self-reported history of hip problem (8/37) had significantly lower HOOS subscores for pain ($P = 0.006$) and quality of life (QoL) ($P = 0.0001$)	Purpose: to evaluate the impact of hip related injuries on the quality of life of professional ballet dancers
			Participants completes the Hip Disability and Osteoarthritis Outcome Score (HOOS)

TABLE 2. Studies Reporting Prevalence of Hip Pathology in Artistic Athletes *(Continued)*

Reference	Participants	Study Findings	Comments
Laible et al[15]	653 dancers evaluated over a 3-yr period	49/653 (7.5%) were diagnosed and treated for iliopsoas syndrome	
		Incidence based on dance level: Students dancers: 14%; Amateur dancers: 7.5%; Professional dancers: 4.6%	
Winston et al[14]	87 elite ballet dancers	91% reported snapping hip	
		Clinicians palpated 46/50 self-reported snapping hips	
		29/46 (46%) hips were diagnosed by radiologists using ultrasound examination	
Askling et al[23]	98 ballet dancers (76 females, 22 males); mean age: 21 yr old (17-25)	Self-reported Hamstring injury: 50/98 (51%) dancers	

MRI, magnetic resonance imaging.

reported intra-articular hip pathology was the chondrolabral injury. Regarding the extra-articular lesions, muscle injuries and especially psoas pathology were mainly observed. The risk factors for these injuries remain unknown. However, the compensated turnout and 2 functional tests ("KLAT" and "Standing bow") have been shown to be predictive of lower extremity injury (including hip) in dancers.[30,33]

Several articles in our review have shown intra-articular hip pathologies such as labral tears, cartilage injuries, and ligamentum teres injuries among artistic athletes,[10,12,13] however, only one article showed the prevalence of FAI in dancers; pincer lesions were seen in 74% of professional ballet dancers (21 men and 26 women), and cam lesion was observed only 26%. However, the correlation between FAI and intra-articular pathology was not investigated in this study.[26]

One possible strong candidate as the cause of intra-articular pathologies in artistic athletes that has yet to be recognized is hip instability or microinstability and joint dysplasia. Prevalence of hip dysplasia in dancers varied in our review. Mitchell et al[34] and Harris et al[26] reported a mean CE angle of the professional ballet dancers to be 21-24 degrees. Duthon et al[24] showed that the mean acetabular depth in professional ballet dancers was lower than in controls, but no significant difference was identified (7.8 vs 8.8 mm, P = 0.065). Mayes et al10 compared CE angle of professional ballet dancers with that of control using magnetic resonance imaging (MRI); the mean CE angle was 29 degrees in ballet dancers without significant difference reported between the groups. Furthermore, a recent article[29] showed that subluxation of the hip occurs in split position (positive vacuum sign in splits radiograph). This interesting phenomenon, which is an indication of hip microinstability, was significantly more common in female dancers than in males. As expected, we found some case reports regarding the dislocation of the hip in dancers but was often the result of an extreme hip maneuver.[35–37] Thus, laxity of the hip joint, (micro) instability, and dysplasia can truly be common causes of injuries in artistic athletes. In contrast, a recent systematic review[38] of groin pain in athletes did not list any of the above in the top 5 pathologies for athletes to undergo hip surgery. Further research regarding hip instability and dysplasia in artistic athletes are necessary to understand the special conditions and true pathologies of their hip.

A recent meta-analysis[38] that focused on the surgical treatment in athletes with groin pain showed that hip arthroscopy for FAI and labral pathology was performed in 97% of patients. Athletic pubalgia was treated with open surgical procedures 70% of the times. The majority (70%) of adductor-related pathology was surgically treated with complete adductor tenotomy, and less than 1% of patients were treated with adductor reattachment procedures. Overall, 36%

TABLE 3. Risk Factors for Lower Extremity/Hip Injury in Artistic Athletes

Reference	Participants	Study Findings	Comments
van Merkensteijn and Quin[33]	22 modern dancers; male = 2 female = 20; mean age: 21.27 yr (19-23)	Significant relationship was found between the degree of compensated turnout (CTO) and the number of lower extremities injuries (r = 0.45, N = 22, *P* = 0.04)	Hip injuries represented 29% of the lower extremity injuries
		Increased CTO was significantly related to traumatic injury but not to overuse injury rate	
Roussel et al[30]	32 modern dancers; male = 6 female = 26; mean age: 20 yr (17-25)	"KLAT" and "Standing bow" lumbopelvic movement test are associated with an increased risk of developing lower extremities or lumbar spine injuries in dancers no relationship was found between generalized joint hypermobility or history of low back pain and injury	Hip injuries represented 12% of the injury rate

of all inguinal pathology was treated with open hernia repair and 39% (183/473) with laparoscopic hernia repair. There was a lack of outcomes scores and standardization methods, and therefore, it was difficult to establish comparisons.

We observed in our systematic review that surgical treatment is preferred in patients with intra-articular and traumatic pathologies and nonoperative treatment in patients with extra-articular and overuse pathologies in artistic sports. However, it was impossible to suggest specific treatment options in artistic athletes because we could not find any randomized control trials, or comparative case series on that subject. In addition, there was a lack of consensus regarding the methods used to evaluate the clinical results, therefore, it was difficult to perform establish comparisons between the various treatments. Standardization of the methods to report the clinical outcomes and the definitions to describe the actual hip pathology (general terms such as "groin" pain should be avoided) is necessary.

Furthermore, we could not find any studies investigating the relationship between bony abnormality, instability, and intra-articular/extra-articular pathologies among artistic athletes. This is the main reason that effective diagnostic algorithms or treatment protocols have not been established, yet, for this population.

LIMITATIONS

There were several limitations in this study, primarily because of the limited available literature on this subject. The heterogeneity between the studies made performing a meta-analysis unfeasible. The lack of randomized clinical trials and comparative case series studies also contributed to that issue. Another limitation is that most studies use different medical terms to report the hip/groin pathology in this population, and therefore, the interpretation of the results was difficult. In addition, many of the studies relied on questionnaires and the hip injuries that were self-reported and often not confirmed by a clinician. The fact that few studies focused exclusively on the artistic population and hip pathology made the data extraction process extremely complicated when the source of information was a study on athletes from different sports reporting injuries in many different joints (including hip). Risk factor analysis models does not exist, and therefore, this study cannot propose prevention methods. The lack of treatment and clinical outcomes studies represents one of the major problems in the artistic athletes' literature regarding the hip pathology. There is not a standardized method of reporting the clinical outcomes on this subject, for example a functional hip score, and therefore, no assumptions can be made.

CONCLUSIONS

Higher quality studies are necessary to identify the pathology and optimize the clinical care of hip injuries in artistic athletes. Prospective comparative cohort studies are necessary to identify the specific pattern of hip injuries, whereas risk analysis retrospective studies will help develop prevention protocols.

FAI and periarticular muscle injuries are commonly reported pathologic findings in artistic athletes, yet, the risk factors are not identified. Treatment and clinical outcomes are underreported and this represents a significant problem when treating these athletes. Collection of long-term outcome data is urgent to identify whether a treatment is beneficial or not in these challenging patients.

References

1. Morelli V, Weaver V. Groin injuries and groin pain in athletes: part 1. *Prim Care*. 2005;32:163–183.
2. Pettine KA. Association of anabolic steroids and avascular necrosis of femoral heads. *Am J Sports Med*. 1991;19:96–98.
3. Gwathmey FW, Byrd JWT. Hip pathology that can cause groin pain in athletes: diagnosis and management. In: Diduch DR, Brunt LM, eds *Sports Hernia and Athletic Pubalgia: Diagnosis and Treatment*. Boston, MA: Springer US; 2014:31–54.
4. Burnett RS, Della Rocca GJ, Prather H, et al. Clinical presentation of patients with tears of the acetabular labrum. *J Bone Joint Surg Am*. 2006; 88:1448–1457.
5. Turner R, O'Sullivan E, Edelstein J. Hip dysplasia and the performing arts: is there a correlation? *Curr Rev Musculoskelet Med*. 2012;5:39–45.
6. Mayes S, Ferris AR, Smith P, et al. J. Bony morphology of the hip in professional ballet dancers compared to athletes. *Eur Radiol*. 2016. doi: 10.1007/s00330-016-4667-x.
7. Gittoes MJR, Irwin G. Biomechanical approaches to understanding the potentially injurious demands of gymnastic-style impact landings. *Sports Med Arthrosc Rehabil Ther Technol*. 2012;4:4.
8. Stull JD, Philippon MJ, LaPrade RF. "At-risk" positioning and hip biomechanics of the Peewee ice hockey sprint start. *Am J Sports Med*. 2011 (39 suppl):29s–35s.
9. Slim K, Nini E, Forestier D, et al. Methodological index for non-randomized studies (minors): development and validation of a new instrument. *ANZ J Surg*. 2003;73:712–716.
10. Mayes S, Ferris AR, Smith P, et al. Atraumatic tears of the ligamentum teres are more frequent in professional ballet dancers than a sporting population. *Skelet Radiol*. 2016;45:959–967.
11. Papavasiliou A, Siatras T, Bintoudi A, et al. The gymnasts' hip and groin: a magnetic resonance imaging study in asymptomatic elite athletes. *Skelet Radiol*. 2014;43:1071–1077.
12. Mayes S, Ferris AR, Smith P, et al. Similar prevalence of acetabular labral tear in professional ballet dancers and sporting participants. *Clin J Sport Med*. 2016;26:307–313.
13. Mayes S, Ferris AR, Smith P, et al. Professional ballet dancers have a similar prevalence of articular cartilage defects compared to age- and sex-matched non-dancing athletes. *Clin Rheumatol*. 2016;35:1–7.
14. Winston P, Awan R, Cassidy JD, et al. Clinical examination and ultrasound of self-reported snapping hip syndrome in elite ballet dancers. *Am J Sports Med*. 2007;35:118–126.
15. Laible C, Swanson D, Garofolo G et al. Iliopsoas syndrome in dancers. *Orthop J Sports Med*. 2013. doi: 10.1177/2325967113500638.
16. Sauer G, Gutgesell M. Ballet dancer with hip and groin pain: Crohn disease and psoas abscess. *Clin Pediatr*. 2005;44:731–733.
17. Rehmani R, Endo Y, Bauman P, et al. Lower extremity injury patterns in elite ballet dancers: ultrasound/MRI imaging features and an institutional overview of therapeutic ultrasound guided percutaneous interventions. *HSS J*. 2015;11:258–277.
18. Masquijo JJ, Sartori F. Myositis ossificans circumscripta of the psoas muscle due to overuse in an adolescent gymnast. *J Pediatr Orthop B*. 2014;23:529–532.
19. Hodnett PA, Shelly MJ, MacMahon PJ, et al. MR imaging of overuse injuries of the hip. *Magn Reson Imaging Clin North Am*. 2009;17: 667–679.
20. Askling CM, Tengvar M, Saartok T, et al. Acute first-time hamstring strains during slow-speed stretching: clinical, magnetic resonance imaging, and recovery characteristics. *Am J Sports Med*. 2007;35:1716–1724.
21. Askling CM, Tengvar M, Saartok T, et al. Proximal hamstring strains of stretching type in different sports: injury situations, clinical and magnetic resonance imaging characteristics, and return to sport. *Am J Sports Med*. 2008;36:1799–1804.
22. Askling C, Tengvar M, Saartok T, et al. Sports related hamstring strains—two cases with different etiologies and injury sites. *Scand J Med Sci Sports*. 2000;10:304–307.
23. Askling C, Lund H, Saartok T, et al. Self-reported hamstring injuries in student-dancers. *Scand J Med Sci Sports*. 2002;12:230–235.
24. Duthon VB, Charbonnier C, Kolo FC, et al. Correlation of clinical and magnetic resonance imaging findings in hips of elite female ballet dancers. *Arthroscopy*. 2013;29:411–419.
25. Gamboa JM, Roberts LA, Maring J, et al. Injury patterns in elite preprofessional ballet dancers and the utility of screening programs to

identify risk characteristics. *J Orthop Sports Phys Ther*. 2008;38: 126–136.
26. Harris JD, Gerrie BJ, Varner KE, et al. Radiographic prevalence of dysplasia, cam, and pincer deformities in elite ballet. *Am J Sports Med*. 2016;44:20–27.
27. Kauther MD, Wedemeyer C, Wegner A, et al. Breakdance injuries and overuse syndromes in amateurs and professionals. *Am J Sports Med*. 2009;37:797–802.
28. Larson AN, Kim HKW, Herring JA. Female patients with late-onset Legg-Calvé-Perthes disease are frequently gymnasts: is there a mechanical etiology for this subset of patients? *J Pediatr Orthop*. 2013;33:811–815.
29. Mitchell RJ, Gerrie BJ, McCulloch PC, et al. Radiographic evidence of hip microinstability in elite ballet. *Arthroscopy*. 2016;32:1038–1044e1031.
30. 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. *Man Ther*. 2009;14:630–635.
31. Stracciolini A, Casciano R, Friedman HL, et al. A closer look at overuse injuries in the pediatric athlete. *Clin J Sport Med*. 2015;25:30–35.
32. Stracciolini A, Yen YM, D'Hemecourt PA, et al. Sex and growth effect on pediatric hip injuries presenting to sports medicine clinic. *J Pediatr Orthop B*. 2016;25:315–321.
33. van Merkensteijn GG, Quin E. Assessment of compensated turnout characteristics and their relationship to injuries in university level modern dancers. *J Dance Med Sci*. 2015;19:57–62.
34. Mitchell JC, Giannoudis PV, Millner PA, et al. A rare fracture-dislocation of the hip in a gymnast and review of the literature. *Br J Sports Med*. 1999; 33:283–284.
35. Buyls IRAE, Rietveld ABM, Ourila T, et al. Total hip replacement in dancers. *Clin Rheumatol*. 2013;32:511–514.
36. Epstein DM, Rose DJ, Philippon MJ. Arthroscopic management of recurrent low-energy anterior hip dislocation in a dancer: a case report and review of literature. *Am J Sports Med*. 2010;38:1250–1254.
37. Khoo-Summers L, Bloom NJ. Examination and treatment of a professional ballet dancer with asuspected acetabular labral tear: a case report. *Man Ther*. 2015;20:623–629.
38. de Sa D, Holmich P, Phillips M, et al. Athletic groin pain: a systematic review of surgical diagnoses, investigations and treatment. *Br J Sports Med*. 2016;50:1181–1186.
39. Yin AX, Sugimoto D, Martin DJ, et al. Pediatric dance injuries: a cross-sectional epidemiological study. *PM R*. 2016;8:348–355.
40. van Dijk CN, Lim LS, Poortman A, et al. Degenerative joint disease in female ballet dancers. *Am J Sports Med*. 1995;23:295–300.
41. Gross C, Rho ME, Aguilar D, et al. Self-reported hip problems in professional ballet dancers: the impact on quality of life. *PM R*. 2016;8(9 suppl):S200.
42. Wright J, Swiontkowski MF, Heckman, JD. Levels of Evidence for Primary Research Question as Adopted by the North American Spine Society. *J Bone Joint Surg*. 2005;85:1–3.

APPENDIX 1. Section 1 Simple Review Studies (Qualitative)

1. Weber AE, Bedi A, Tibor LM, et al. The hyperflexible hip: managing hip pain in the dancer and gymnast. *Sports Health.* 2015;7:346–358.
2. Rehmani R, Endo Y, Bauman P, et al. Lower extremity injury patterns in elite ballet dancers: ultrasound/MRI imaging features and an institutional overview of therapeutic ultrasound guided percutaneous interventions. *HSS J.* 2015;11: 258–277.
3. Moser BR. Hip pain in dancers. *Curr Sports Med Rep.* 2014;13: 383–389.
4. Angioi M, Maffulli GD, McCormack M, et al. Early signs of osteoarthritis in professional ballet dancers: a preliminary study. *Clin J Sport Med.* 2014;24:435–437.
5. Rietveld ABM. Dancers' and musicians' injuries. *Clin Rheumatol.* 2013;32:425–434.
6. Porter EB. Common injuries and medical problems in singles figure skaters. *Curr Sports Med Rep.* 2013;12: 318–320.
7. Chang GH, Paz DA, Dwek JR, et al. Lower extremity overuse injuries in pediatric athletes: clinical presentation, imaging findings, and treatment. *Clin Imaging.* 2013;37:836–846.
8. Turner R, O'Sullivan E, Edelstein J. Hip dysplasia and the performing arts: is there a correlation? *Curr Rev Musculoskelet Med.* 2012;5:39–45.
9. Rickman AM, Ambegaonkar JP, Cortes N. Core stability: implications for dance injuries. *Med Probl Perform Artists.* 2012; 27:159–164.
10. Rehmani R, Adler R. Lower extremity injury patterns in elite ballet dancers: MR imaging with ultrasound correlation and ultrasound–guided interventions. *AJR Am J Roentgenol.* 2012; 198(5 suppl 1).
11. Martinez N, Mandel S, Peterson JR. Neurologic causes of hip pain in dancers. *J Dance Med Sci.* 2011;15:157–159.
12. Kern-Scott R, Peterson JR, Morgan P. Review of acetabular labral tears in dancers. *J Dance Med Sci.* 2011;15:149–156.
13. Chow AH, Morrison WB. Imaging of hip injuries in dancers. *J Dance Med Sci.* 2011;15:160–172.
14. Kimmerle M. Lateral bias, functional asymmetry, dance training and dance injuries. *J Dance Med Sci.* 2010;14:58–66.
15. Karim A. Sacroiliac joint dysfunction in a male professional contemporary dancer with low back pain. *J Man Manip Ther.* 2010;18:227–228.
16. Deleget A. Overview of thigh injuries in dance. *J Dance Med Sci.* 2010;14:97–102.
17. Hodnett PA, Shelly MJ, MacMahon PJ, et al. MR Imaging of Overuse Injuries of the Hip. *Magn Reson Imaging Clin North Am.* 2009;17:667–679.
18. Porter EB, Young CC, Niedfeldt MW, et al. Sport-specific injuries and medical problems of figure skaters. *Wisc Med J.* 2007;106:330–334.
19. Torry MR, Schenker ML, Martin HD, et al. Neuromuscular hip biomechanics and pathology in the athlete. *Clin Sports Med.* 2006;25:179–197.
20. Motta-Valencia K. Dance-related injury. *Phys Med Rehabil Clin N Am.* 2006;17:697–723.
21. Miller C. Dance medicine: current concepts. *Phys Med Rehabil Clin N Am.* 2006;17:803–811.
22. To WW, Wong MW, Lam IY. Bone mineral density differences between adolescent dancers and non-exercising adolescent females. *J Pediatr Adolesc Gynecol.* 2005;18:337–342.
23. Lequesne M. Sport practice and osteoarthritis of the limbs. *Sci Sports.* 2004;19:281–285.
24. Philippon MJ. The role of arthroscopic thermal capsulorrhaphy in the hip. *Clin Sports Med.* 2001;20:817–829.
25. Jaffré C, Courteix D, Dine G, et al. High-impact loading training induces bone hyperresorption activity in young elite female gymnasts. *J Pediatr Endocrinol Metab.* 2001;14: 75–83.
26. Bennell K, Khan K, Matthews B, et al. Activity-associated differences in bone mineral are evident before puberty: a cross-sectional study of 130 female novice dancers and controls. *Pediatr Exerc Sci.* 2000;12:371–381.
27. Wu J, Ishizaki S, Kato Y, et al. The side-to-side differences of bone mass at proximal femur in female rhythmic sports gymnasts. *J Bone Miner Res.* 1998;13:900–906.
28. DeMann Jr LE. Sacroiliac dysfunction in dancers with low back pain. *Manual Therapy.* 1997;2:2–10.
29. Weiss DS, Zlatkowski M. Rehabilitation of dance injuries to the shoulder, lumbar spine, pelvis, and hip. *Orthop Phys Ther Clin North Am.* 1996;5:477–496.

30. Schon LC, Weinfeld SB. Lower extremity musculoskeletal problems in dancers. *Curr Opin Rheumatol.* 1996;8:130–142.
31. Khan KM, Green RM, Saul A, et al. Retired elite female ballet dancers and nonathletic controls have similar bone mineral density at weightbearing sites. *J Bone Miner Res.* 1996;11: 1566–1574.
32. Khan K, Brown J, Way S, et al. Overuse Injuries in Classical Ballet. *Sports Med.* 1995;19:341–357.
33. Milan KR. Injury in ballet: a review of relevant topics for the physical therapist. *J Orthop Sports Phys Ther.* 1994;19:121–129.
34. Lorei MP, Hershman EB. Peripheral Nerve Injuries in Athletes: treatment and Prevention. *Sports Med.* 1993;16:130–147.
35. Karlsson MK, Johnell O, Obrant KJ. Bone mineral density in professional ballet dancers. *Bone Miner.* 1993;21:163–169.
36. Reid DC. Prevention of Hip and Knee Injuries in Ballet Dancers. *Sports Med.* 1988;6:295–307.

Figure 1