Clinical presentation, imaging findings, and arthroscopic features in skeletally immature and mature adolescent hip patients: a comparative double-cohort retrospective study

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The purpose of this study was to evaluate differences in clinical presentation and extent of surgery required based on skeletal maturity between two cohorts of adolescent hip arthroscopy patients. We hypothesized that skeletal immaturity would be associated with a lower frequency of pincer impingement and a decreased need for surgical acetabuloplasty. A database of 1481 hip arthroscopies performed by a single orthopaedic surgeon between 2008 and 2016 was queried. Patients ≤18 years of age with femoroacetabular impingement were divided into two groups based on Risser score: Risser 1–4 (skeletally immature) or Risser 5 (skeletally mature). Groups were compared with respect to presentation, diagnosis, and arthroscopic procedures performed. Eighty-eight skeletally immature and 49 skeletally mature patients were included. Mixed impingement was more common in skeletally mature patients than immature (67.3% vs. 48.9%, *P* = 0.037). Skeletal maturity was associated with a significantly increased probability of undergoing acetabuloplasty (odds ratio = 4.6, 95% confidence interval 1.4–15.5; *P* = 0.014). Extent of chondral degeneration was similar between groups. Our findings support the hypothesis that skeletally immature hips undergo acetabuloplasty less frequently and demonstrate similar chondromalacia compared with a skeletally mature cohort. These results suggest that arthroscopic treatment for impingement-associated hip pain may be a reasonable option to consider for symptomatic skeletally immature patients who have completed a structured course of nonoperative treatment. Additional longitudinal outcomes data are needed to clarify the natural history of impingement-associated hip pain in younger populations and whether hip arthroscopy delays progression of osteoarthritis in these patients. *J Pediatr Orthop B* 30: 316–323 Copyright © 2021 Wolters Kluwer Health, Inc. All rights reserved.

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Introduction

Femoroacetabular impingement (FAI) in the adolescent hip is an increasingly recognized pathology [1–3]. Factors that have contributed to greater awareness of FAI include advancements in technology (e.g. improvements in diagnostic imaging), improvements in physical examination, expanded understanding of proper hip mechanics and anatomy, increased sports-related injuries in young people, greater appreciation of hip pathologies in adolescent patients, and expanded understanding of factors that predispose the hip to degenerative changes [1,3–5]. Previous studies have reported FAI to be the most common cause of hip pain, altered range of motion in the hip joint, and diminished performance among athletes [5]. The two basic types of FAI are the morphological abnormalities of the acetabulum (pincer lesion) or proximal femur (cam lesion). However, more often patients have a combination or mixed-type impingement (cam and pincer) [6,7]. FAI can contribute to intra-articular damage and the development of early-onset osteoarthritis, and may be corrected surgically by hip arthroscopy [7–10].

Hip arthroscopy is increasingly popular in adult populations for the treatment of pre-arthritic hip conditions such as FAI [11]. Greater knowledge of the underlying pathophysiology and considerable advancements in surgical instrumentation, techniques, and corrective options have also led to increased utilization of arthroscopy to treat impingement in adolescents [1], with

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indications analogous to those for adult patients [3]. Numerous studies have reported favorable outcomes using arthroscopy to treat a variety of hip pathologies in the adolescent population [1,3,12–20]. Despite reports of successful arthroscopic treatment in adolescents, there are important differences between adolescent and adult hip patients that are increasingly recognized but not yet fully understood. Presently, there is paucity of the evidence-based literature with regards to the impact of skeletal maturity on the natural history and operative management of intra-articular hip pathology, such as FAI [3]. Recent evidence supports a possible higher risk for development of cam deformities just prior to physeal closure [21]. There is also increasing evidence that pincer lesions may develop during later phases of skeletal maturation [22,23]. In addition, pathologic radiographic values of FAI in the pediatric population are inconclusive, and the link between pathology and operative management of FAI in these patients is arbitrary [7]. Accordingly, evaluation of the effect(s) of skeletal maturity on intra-articular hip pathology is necessary in order to optimize treatment algorithms in adolescent patients.

The purpose of this study was to assess differences in clinical presentation and extent of surgery required on the femur or acetabulum based on skeletal maturity between two cohorts of adolescent patients at the time of hip arthroscopy. We hypothesized that skeletal immaturity would be associated with a lower frequency of pincer impingement and a decreased need for surgical acetabuloplasty.

Methods

A prospective database of 1481 consecutive hip arthroscopies performed between 2008 and 2016 by a single, fellowship-trained orthopedic surgeon was queried. Patients were enrolled in an Institutional Review Board-approved study prior to surgery. Inclusion criteria for this study were adolescent males and females 18 years of age or younger at the time of surgery who presented with hip pain along with clinical signs and symptoms of FAI and who failed a structured course of non-operative management. Specifically, prior to offering patients surgery the senior author employs 3 or more months of non-operative management, which consists of avoidance of painful activities, 6 or more weeks of anti-inflammatory medications, and 6 or more weeks of hip and core-specific physical therapy. Activities are restricted to activities of daily living, which for the adolescent population includes school, travel, and family activities. Activities such as physical education class, intensive exercise (e.g. personal training, gym, or fitness programs), and sports are avoided. In cases where hip injections are performed for diagnostic or health insurance-based protocols, we use intra-articular triamcinolone 40 mg/ml (1 ml) and ropivacaine 0.25% (2.5 ml). Injections are performed with image guidance, typically fluoroscopy, and are typically limited to a single attempt.

Patients with a history of hip surgery (open or arthroscopic), hip dysplasia [lateral center-edge angle (of Wiberg) less than 20°], avascular necrosis of the femoral head, slipped capital femoral epiphysis (SCFE), diffuse (>20 mm^2) femoral head chondromalacia, or chronicity of symptoms for less than 90 days were excluded from this study. Patients who met the inclusion criteria were then stratified into two groups based on Risser score assessed on anteroposterior radiographs: Risser 1–4 (skeletally immature) or Risser 5 (skeletally mature). Risser score is an established and reliable tool used to gauge skeletal maturity. This staging system delineates ossification and fusion of the iliac apophysis into six stages (Risser 0–5). Stages 0–3 involve progressively greater ossification of the iliac wing [24]. Stage 4 indicates the time period when fusion of the apophysis and iliac wing commences [24]. Finally, stage 5 indicates complete fusion of the apophysis with the iliac wing ('skeletal maturity') [24]. Groups were compared with respect to patient demographics, clinical presentation [laterality, location of hip pain, presence of low back pain, pain with activity, presence of mechanical symptoms, duration of symptoms, use of nonsteroidal anti-inflammatory drugs (NSAIDs) or narcotic pain medications, or previous physical therapy], diagnostic imaging findings, intraoperative assessment of pathology, and arthroscopic procedures performed.

An initial diagnosis of FAI syndrome was made based on preoperative clinical and radiographic findings and confirmed intraoperatively. Clinical findings included pain lasting at least 90 days, asymmetric hip motion deficits in supine terminal hip flexion, internal rotation, and flexion, abduction, and external rotation testing. Further, flexion, adduction, and internal rotation impingement testing was assessed for pain. Patients with symmetric spine, hip, and knee motion but associated bilateral tightness of iliopsoas, iliotibial band, or hamstrings were treated non-operatively with physical therapy.

On preoperative plain film radiographs, a patient with an alpha angle greater than 55° on a plain film lateral hip view was considered to have cam impingement [25]. Evidence of hip over-coverage included a lateral center-edge angle greater than 40° on an anteroposterior view [26], center of rotation of femoral head medial to posterior wall projection on an anteroposterior view, and the medial wall of the acetabulum projecting medial to the ilioischial line on an anteroposterior view. A patient with two-out-of-three of these radiographic findings was considered to have profunda pincer impingement. Cephalad acetabular crossover sign on an anteroposterior view was deemed consistent with acetabular retroversion and pincer impingement.

MRI findings were utilized to evaluate labral and chondral pathology. Internally-sourced MRI was performed without contrast and utilizing T1 and T2 fat-suppressed sequencing with three orthogonal fields of view. Externally referred patients with accompanying MRI were analyzed with existing imaging whenever practical; in the event that existing images were of poor quality or not sequenced for specific hip joint assessment, new imaging studies were performed at our institution. Preoperative assessment of chondral lesions was assessed as either positive or negative for chondromalacia along with the femoral head or acetabular surfaces. The presence or absence of subchondral bone edema or cystic changes was noted as well, as these findings are predictive of full-thickness chondral injury at the time of surgery.

All arthroscopic procedures were performed by a single surgeon. Patient positioning, surgical approach, and diagnostic arthroscopic examination were performed as described previously [27,28]. Arthroscopic assessment allowed for confirmation of impingement type and further characterization of chondral lesions including grade, size, and location. The decision to perform acetabular or femoral decompression to address underlying pincer or cam impingement was based on preoperative imaging, dynamic intraoperative fluoroscopic assessment, and arthroscopic evaluation. Specifically, acetabuloplasty was performed in the setting of radiographic retroversion or profunda morphology when the anterior and lateral center edge angles were greater than 25° and intraoperative findings of labral intrasubstance injury corresponding with dynamic conflict. Further, cam femoroplasty was performed in the setting of radiographic alpha angle of greater than 50° and intraoperative findings of acetabular chondromalacia corresponding with dynamic conflict. Chondral lesion severity was quantified using a previously reported chondromalacia severity index (CMI), defined as the product of the Outerbridge chondromalacia grade (I–IV) and the affected surface area (mm^2) for each chondral lesion [29]. The specific arthroscopic procedures utilized for each patient were also documented (e.g. femoroplasty, microfracture, labral repair).

Statistical analysis

IBM SPSS Statistics software (version 24.0; IBM Inc., Armonk, New York, USA) was used for all statistical analyses. Chi-square and Student's *t*-test analysis was used for categorical and continuous variables, respectively. Predictors of chondral lesion grade, size, and severity were identified using multivariate linear regression analysis. The increased probability of a particular arthroscopic treatment between skeletally mature and immature patients was assessed using binary logistic regression, yielding an odds ratio (OR) and corresponding 95% confidence interval (CI). For all statistical analyses, the threshold for significance was established at $P < 0.05$. Numerical values given are mean ± SD unless noted otherwise.

Table 1 Patient demographics and clinical presentation based on skeletal maturity

	Skeletally immature	Skeletally mature	*P* value
Number of patients	88 (64.2%)	49 (35.8%)	
Age (years)[a]	16.3 ± 1.2	16.9 ± 1.1	**0.031**
Females[a]	70 (80.5%)	31 (63.3%)	**0.028**
BMI (kg/m^2)	23.8 ± 7.9	22.7 ± 2.6	0.455
Laterality			
Right hip	29 (59.2%)	24 (57.1%)	0.844
Location of pain			
Anterior/anterolateral	44 (89.8%)	41 (97.6%)	0.134
Lateral	3 (6.1%)	1 (2.4%)	0.385
Posterior/posterolateral	10 (20.4%)	6 (14.3%)	0.444
Lower back pain	17 (34.7%)	18 (42.9%)	0.425
Pain with activity			
Low impact[b]	50 (56.8%)	34 (69.4%)	0.359
High impact[a,c]	34 (38.6%)	8 (16.3%)	**0.007**
Mechanical symptoms[a]	68 (77.3%)	22 (44.9%)	**<0.001**
Duration of symptoms (months)	21.0 ± 26.2	19.1 ± 22.7	0.718
Pain medications			
NSAIDs	46 (93.8%)	42 (100.0%)	0.396
Narcotics[a]	7 (14.7%)	24 (57.1%)	**0.001**
Physical therapy	35 (71.7%)	28 (66.7%)	0.620

Bold values are meant to denote significance.
NSAIDs, nonsteroidal anti-inflammatory drugs.
[a]Denotes significance, $P \leq 0.05$.
[b]Low impact activities included bending, sitting, standing, and yoga.
[c]High impact activities included walking, running (including participation in sports), squatting, and stairs.

Results

A total of 137 patients met the inclusion criteria for this study, including 88 (64.2%) skeletally immature and 49 (35.8%) skeletally mature patients (Table 1). On average, skeletally immature patients were younger than skeletally mature patients (16.3 ± 1.2 years vs. 16.9 ± 1.1 years, $P = 0.031$). The skeletally immature group had a significantly higher proportion of females compared with the skeletally mature group (80.5% vs. 63.3%, $P = 0.028$). In addition, skeletally immature patients more commonly experienced pain with high impact activities (38.6% vs. 16.3%, $P = 0.007$) and more often reported mechanical symptoms (77.3% vs. 44.9%, $P < 0.001$) compared with skeletally mature patients. Patient groups were similar with respect to BMI, laterality and location of pain, frequency of lower back pain and pain with low impact activity, duration of symptoms, use of NSAIDs, and proportion of patients who previously underwent physical therapy. A significantly lower proportion of skeletally immature patients were prescribed narcotics compared with skeletally mature patients (14.7% vs. 57.1%, $P = 0.001$). The average Risser score for the skeletally immature cohort was 3.8 ± 0.49, which was significantly lower than the skeletally mature cohort ($P < 0.001$) (Table 2). Radiographic measurements and MRI pathology (e.g. labral tears) did not significantly differ between groups.

Arthroscopic assessment confirmed that mixed impingement was the most common impingement type identified, with a significantly higher proportion of mixed impingement in skeletally mature patients compared with skeletally immature patients (67.3% vs. 48.9%,

P = 0.037) (Table 3). Acetabular and femoral chondral lesion grade, size, location, and severity did not significantly differ between patient groups. The stratification of patients based on Risser score, including impingement type and procedure(s) performed, is presented in Table 4.

Acetabuloplasty was performed less frequently for skeletally immature patients compared with skeletally mature patients (56.8% vs. 79.5%, P = 0.03) (Fig. 1). Nearly all patients in both cohorts underwent femoroplasty to address cam deformity (96.6% and 93.9% for skeletally immature and mature, respectively; P = 0.457). Chondral defects were preferentially treated with chondroplasty in both skeletally immature and mature patients (95.7 and 92.5%, respectively; P = 0.533), while microfracture was used relatively infrequently in both groups (4.3 and 5.0%, respectively; P = 0.886). The frequency of other arthroscopic interventions did not differ between groups. After adjusting for patient age, sex, and BMI, skeletal maturity was associated with an increased probability of undergoing acetabuloplasty (OR = 4.6, 95% CI 1.4–15.5; P = 0.014) compared with skeletally immature patients.

Multivariate linear regression demonstrated that among adolescent patients, male sex was an independent predictor of more severe acetabular chondral lesion grade, size, and CMI (Table 5). Age, BMI, and duration of hip pain failed to predict chondral lesion grade, size, or severity. Impingement type was not a significant predictor of chondral lesion pathology or duration of preoperative hip pain.

Table 2 Findings from preoperative diagnostic imaging studies based on skeletal maturity

	Skeletally immature	Skeletally mature	P value
Radiographic measurements			
Risser score[a]	3.8 ± 0.49	5.0 ± 0.0	**<0.001**
Lateral center-edge angle (degrees)	27.8 ± 7.5	28.2 ± 4.1	0.788
Sharp's angle (degrees)	41.6 ± 4.4	40.9 ± 2.5	0.419
Anterior center-edge angle (degrees)	29.9 ± 9.4	29.6 ± 5.9	0.826
Alpha angle (degrees)	67.2 ± 5.7	65.4 ± 7.6	0.374
MRI findings			
Acetabuluar retroversion	42 (84.8%)	36 (85.7%)	0.939
Acetabular labral tear	49 (100.0%)	39 (92.3%)	0.118
Acetabular chondromalacia	26 (53.6%)	32 (75.0%)	0.205
Acetabular subchondral cyst	3 (7.1%)	4 (9.1%)	0.837

Bold value is meant to denote significance.
[a]Denotes significance, $P \leq 0.05$.

Table 3 Arthroscopic assessment based on skeletal maturity

	Skeletally immature	Skeletally mature	P value
Impingement type			
Cam	37 (42.0%)	11 (22.4%)	0.062
Pincer	8 (9.1%)	5 (10.2%)	0.831
Mixed[a]	43 (48.9%)	33 (67.3%)	**0.037**
Chondral lesion grade[b]			
Acetabulum	1.7 ± 0.6	1.9 ± 0.7	0.175
Femoral head	1.5 ± 0.7	1.3 ± 0.6	0.468
Chondral lesion area (mm^2)[b]			
Acetabulum	84.0 ± 37.8	99.6 ± 71.4	0.194
Femoral head	153.8 ± 51.9	160.6 ± 78.4	0.729
Chondral lesion location			
Superior-anterior	19 (39.6%)	15 (36.6%)	0.722
Superior-posterior	30 (60.4%)	27 (63.4%)	
CMI[c]			
Acetabulum (grade × mm^2)	144.8 ± 88.6	232.4 ± 293.5	0.141
Femoral head (grade × mm^2)	286.6 ± 267.1	178.2 ± 103.3	0.149

Bold value is meant to denote significance.
CMI, chondromalacia severity index.
[a]Denotes significance, $P \leq 0.05$.
[b]Represents characteristics of primary lesion (chondral lesion location refers to acetabulum only).
[c]Chondromalacia severity index (CMI) is equal to the product of outerbridge chondromalacia grade (I to IV) and the affected surface area (mm^2) for each chondral lesion.

Discussion

Our study found that mixed impingement was the most common impingement type among adolescent hip arthroscopy patients, with a significantly higher proportion of mixed impingement in skeletally mature patients compared with skeletally immature patients. In addition, we found that skeletally immature hips underwent acetabuloplasty less frequently and demonstrated similar chondromalacia compared with a skeletally mature cohort.

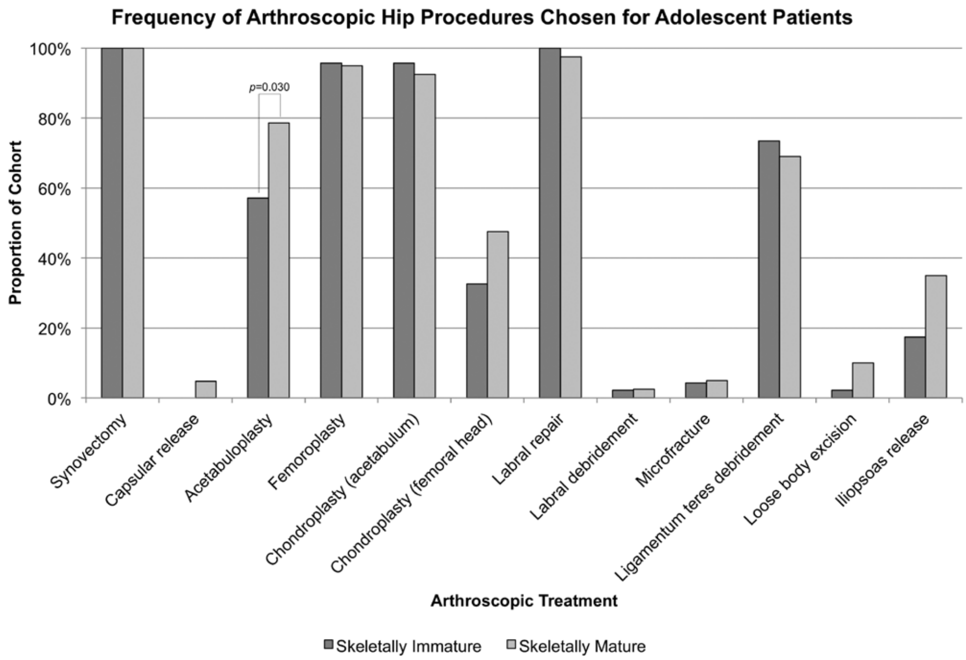
Different pathogenic mechanisms may be responsible for the development of symptomatic cam and pincer deformities during different stages of skeletal development, which may help to explain why mixed impingement was significantly more common in skeletally mature hips. Previous studies have reported that premature closure of the triradiate cartilage complex may inhibit progression of acetabular orientation during later stages of skeletal maturation, resulting in a shallow and more retroverted acetabulum [22]. Further, primary pincer and mixed deformities often occur in the presence of acetabular retroversion [30,31]. In the present study,

Table 4 Stratification of patients based on Risser score, including impingement type and procedure(s) performed

Risser score	1	2	3	4	5
Number of patients	1	4	5	78	49
Impingement type					
Cam	1 (100.0%)	3 (75.0%)	1 (20.0%)	32 (41.0%)	11 (22.4%)
Pincer	0 (0.0%)	0 (0.0%)	0 (0.0%)	8 (10.3%)	5 (10.2%)
Mixed	0 (0.0%)	1 (25.0%)	4 (80.0%)	38 (48.7%)	33 (67.3%)
Acetabuloplasty	1 (100.0%)	1 (25.0%)	4 (80.0%)	44 (56.4%)	39 (79.5%)
Femoroplasty	1 (100.0%)	4 (100.0%)	5 (100.0%)	75 (96.2%)	46 (93.9%)
Combined acetabuloplasty and femoroplasty	1 (100.0%)	1 (100.0%)	4 (80.0%)	49 (62.8%)	38 (77.6%)

Reported percentages reflect the proportion of patients in the associated Risser subgroup (e.g. 1, 2, etc.).

Fig. 1



Comparison of arthroscopic treatments between skeletally immature and skeletally mature adolescent hip arthroscopy patients.

Table 5 Multivariate linear regression analysis to predict primary chondral lesion severity based on patient age, sex, BMI, and duration of hip pain

	Chondral lesion grade			Chondral lesion size			Chondromalacia severity index (CMI)		
R^{2a}									
Acetabulum		**0.257, *P* = 0.001**			**0.299, *P* < 0.001**			**0.297, *P* < 0.001**	
Femoral head		0.143, *P* = 0.294			0.164, *P* = 0.342			0.131, *P* = 0.399	
	β^b	95% CI	*P* value	β^b	95% CI	*P* value	β^b	95% CI	*P* value
Age									
Acetabulum	−0.08	−1.96 to 0.043	0.206	3.7	−7.2 to 14.7	0.499	12.7	−29.5 to 54.9	0.549
Femoral head	0.07	−0.12 to 0.25	0.469	11.2	−8.6 to 31.2	0.258	29.0	−46.2 to 104.2	0.436
Sex (reference female)									
Acetabulum	−0.68	−1.0 to −0.36	**<0.001**	−71.1	−100.0 to −42.4	**<0.001**	−267.9	−378.7 to −157.1	**<0.001**
Femoral head	−0.36	−0.82 to 0.11	0.128	−32.9	−82.7 to 16.8	0.186	−103.9	−291.9 to 84.2	0.267
BMI									
Acetabulum	0.003	−0.03 to 0.03	0.828	−1.4	−3.9 to 1.2	0.289	−5.4	−15.1 to 4.4	0.277
Femoral head	−0.02	−0.05 to 0.02	0.371	−1.7	−5.6 to 2.1	0.366	−8.9	−23.8 to 5.9	0.231
Duration of hip pain									
Acetabulum	0.005	−0.002 to 0.01	0.131	0.31	−0.27 to 0.89	0.292	1.8	−0.44 to 4.0	0.115
Femoral head	0.002	−0.01 to 0.11	0.582	0.15	−0.72 to 1.0	0.726	1.5	−1.9 to 4.9	0.366

Bold values are meant to denote significance.

[a]Coefficient of determination for baseline linear regression model that includes patient age, sex, BMI, and duration of hip pain.

[b]Beta indicates the amount of change expected in the dependent variable (grade, size, or severity) based on a one-unit increase in the independent variable (age, sex, BMI, or duration of hip pain). For example, a one-unit increase in sex (with male arbitrarily assigned as '0' in this study and female arbitrarily assigned as '1' in this study) is expected to result in a significant decrease in acetabular CMI of 267.9 – thus, male sex is said to be an independent predictor of more severe CMI of the acetabulum.

approximately 85% of patients in both groups were found to have retroverted acetabula, which, together with the high prevalence of mixed impingement in both groups, is in concordance with the literature. Current evidence is inconclusive as to whether primary cam lesions arise before or after physeal closure [6,32–34]. There is growing evidence that repetitive microtrauma to the physis, as can result from vigorous athletic activity during adolescence, may play a causal role in the development of cam impingement [6]. Additionally, it has previously been speculated that idiopathic cam morphology may be caused by subclinical SCFE. However, recent evidence has shown drastic differences in the growth plate tilt angle between patients with idiopathic cam morphology and cam morphology secondary to SCFE, suggesting that subclinical SCFE is not a major cause of idiopathic cam lesions [35]. Notwithstanding, patients with history of SCFE were excluded from the present study to minimize confounding factors.

Despite mixed impingement being diagnosed more commonly in skeletally mature patients, arthroscopic management was found to be similar between groups in this study. The one procedure found to have a significantly different frequency between groups was acetabuloplasty, which was performed more often in skeletally mature patients. This finding may shed new light on the role of skeletal maturity in the development of pincer deformity and appropriate surgical management of both mixed and pincer impingement. Correct diagnosis of the underlying pathology causing pincer impingement is crucial and can be influenced by patterns of growth and development [23]. Given the potential pitfalls of diagnosing pincer impingement in young patients and the implications, this has for operative management, in addition to the fact that the proximal femoral physis closes before the acetabular rim has fully matured, our findings support that the focus of treatment in skeletally immature patients should be correction of cam lesion while avoiding the acetabular rim as much as possible. The majority of patients (>95%) in both groups in this study underwent arthroscopic femoroplasty based on intraoperative dynamic assessment of femoroacetabular articulation. Dynamic fluoroscopic assessment of impingement may be more sensitive than plain radiography and the radiographic parameters to diagnose cam-type impingement in adults (e.g. alpha angle >55°) may not translate to adolescent patients [7]. Regardless, intraoperative fluoroscopic and arthroscopic assessment should be performed to diagnose less obvious cam impingement.

Both cam and pincer deformities are associated with acetabular cartilage and labral pathology in adults [8,10,36]. In this study, we observed a similar frequency of labral and acetabular chondral pathology among skeletally mature and immature patients. These results suggest that skeletal immaturity may not confer immunity to pre-arthritic hip conditions. Of note, the frequency of microfracture to treat chondral defects among adolescents in this study (5%) was lower than that reported in the literature for adults (31.2%) [37,38]. This difference may be secondary to the relatively low grade (Outerbridge grade <II) of chondral lesions with which adolescent patients in this study presented.

Our study identified that adolescent males demonstrated larger and more severe chondral defects than females. This finding parallels a previous study that found males were significantly more likely to have evidence of more extensive chondral damage (based on intraoperative Outerbridge grading) than females at the time of arthroscopy [25]. Interestingly, the referenced study also found males were more likely to demonstrate a larger mean alpha angle and more severe cam impingement compared with females, neither of which were found to be significant differences in our study [25]. Given the current lack of data addressing FAI etiology and reliable pathologic radiographic measurements in adolescent hip arthroscopy patients, further investigation is necessary to establish the association between hip morphology, FAI etiology, and chondral pathology.

In conclusion, our findings support the hypothesis that at the time of hip arthroscopy, skeletally immature hips undergo acetabuloplasty less frequently and demonstrate similar chondromalacia compared with a skeletally mature cohort. These results suggest that arthroscopic treatment for impingement-associated hip pain may be a reasonable option to consider for symptomatic skeletally immature patients who have completed a structured course of nonoperative treatment. Additionally, surgical techniques to correct impingement and chondral defects should be mindful of the developing skeleton, particularly the acetabular rim. Finally, male sex was found to be a significant independent predictor of overall chondral lesion grade, size, and severity among adolescent patients in this study. Future studies are warranted to investigate the skeletal maturity- and sex-based differences identified by this study. Additional long-term outcomes data are also needed to clarify the natural history of impingement-associated hip pain in younger populations and whether hip arthroscopy delays osteoarthritis onset in these patients. It is imperative that treating physicians, patients, and parents proceed cautiously. A balance must be made between the results of non-operative management with the recommendation for surgical treatment and its morbidity of possible iatrogenic chondral injury associated with surgical access, exposure, and treatment. All available non-surgical modalities (e.g. activity modification, anti-inflammatory medications, physical therapy, or intra-articular injections) should be considered prior to embarking on surgical intervention, while cautioning patients and parents about the potential risk of worsening chondral damage in untreated symptomatic FAI cases. The results from this study may help improve patient evaluation and selection for surgery and formulate appropriate preventive measures and arthroscopic treatment criteria.

There were several limitations of this study inherent to a retrospective study and that may affect the generalizability of the results. There was the potential for errors and omissions in the database that was queried, which may have introduced confounders and influenced the results. Using the established definition of hip dysplasia (lateral center-edge angle <20°) may have failed to exclude patients with mild hip dysplasia. The size of the study population was relatively small, which also limited the statistical power of our multivariate regression analysis evaluating predictors of chondral lesion severity. Although this study examined a small sample of patients from a single orthopedic surgeon, all measurements were collected in a standardized fashion by the senior author in order to strengthen intraobserver reliability. The small observed differences in average Risser scores and ages between groups, though statistically significant, may have limited clinical significance. Despite the popularity and ease of the Risser classification system for assessing skeletal maturity in the clinical setting, the reliability and accuracy of this method remains debated in part because of the variable appearance of the iliac apophysis [39]. Notwithstanding, although a number of methods for assessing skeletal age have been described that may offer certain advantages over Risser classification, none are without their own unique limitations as well. It is unknown whether any skeletally mature patients included in this study developed hip pathology or became symptomatic prior to physeal closure, which could have influenced the results for both groups. Similarly, it is unknown whether any skeletally mature patients with mixed impingement may have initially had isolated cam or pincer impingement prior to skeletal maturity, then converted to mixed impingement by the time they reached skeletal maturity; if so, this may help to explain the significantly higher proportion of mixed impingement observed in skeletally mature patients in this study. Furthermore, choice of arthroscopic procedure inevitably reflects a degree of surgeon preference, which could have influenced the findings of this study. Follow-up data and patient-reported outcomes were not collected and therefore could not be assessed or correlated with preoperative and operative data. The database only included patients who underwent operative treatment and did not capture or assess adolescent patients with hip pain who did not undergo operative treatment, which possibly resulted in selection bias. Patients in both groups were also predominantly female, which may also have resulted in selection bias.

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Conflicts of interest

A.V.S. – Research support: Smith & Nephew. S.M. – Grants: American Board of Medical Specialties and American Board of Orthopedic Surgery (ABMS-ABOS); Patents: *Tissue tensioning devices and related methods* (U.S. Patent No. 08926626, Awarded January 6, 2015). A.J.S. – Boards/committees: AAOS, ABOS, AOSSM, AANA, ISAKOS, ISHA, MASH Group; Editorial or governing board: Journal of Hip Preservation Surgery; Publishing royalties, financial, or monetary support: Thieme. For the remaining authors, there are no conflicts of interest.

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