Hip Arthroscopy Improves Symptoms Associated with FAI in Selected Adolescent Athletes

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Abstract

Background Femoroacetabular impingement (FAI) is increasingly diagnosed in young and middle-aged patients. Although arthroscopic procedures are becoming frequently used in the treatment of FAI, there are little data regarding rates of complications or the ability of hip arthroscopy to improve hip function specifically in the adolescent athlete population. Because arthroscopic treatment is being used in the treatment of FAI, it is vital to know what, if any, improvements in hip function can be expected and the potential complications.

Questions/purposes We asked (1) whether validated measures of hip function improve after arthroscopic treatment of FAI in adolescent athletes, and (2) what complications might be expected during and after arthroscopic treatment of FAI in these patients.

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Each author certifies that his or her institution approved the human protocol for this investigation, that all investigations were conducted in conformity with ethical principles of research, and that informed consent for participation in the study was obtained.

This work was performed at the Hospital for Special Surgery, New York, NY, USA.

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Methods We retrospectively reviewed the records of 27 hips in 21 patients 19 years of age or younger who underwent arthroscopic treatment for FAI between 2007 and 2008. From the records we extracted demographic data, operative details, complications, and preoperative and postoperative modified Harris hip scores (HHS) and the Hip Outcome Score (HOS). The minimum followup was 1 year (average, 1.5 years; range, 1–2.5 years).

Results Modified HHS improved by an average of 21 points, the activities of daily living subset of the HOS improved by an average of 16 points, and the sports outcome subset of the HOS improved by an average of 32 points. All patients' self-reported ability to engage in their preoperative level of athletic competition improved. In 24 hips that underwent cam decompression, the mean alpha-angle improved from $64^\circ \pm 16^\circ$ to $40^\circ \pm 5.3^\circ$ postoperatively.

Conclusions We found short-term improvements in HOS and HHS with no complications for arthroscopic treatment of FAI in our cohort of adolescent athletes. We believe arthroscopic treatment of FAI by an experienced hip arthroscopist should be considered in selected patients when treating athletically active adolescents for whom nonoperative management fails.

Level of Evidence Level IV, therapeutic study. See Guidelines for Authors for a complete description of levels of evidence.

Introduction

FAI of the hip is a well-described pathologic condition [5, 6, 25, 26, 32, 37, 39–42, 44–46, 49, 53, 58]. Caused by abnormal bony offset at the femoral head-neck junction (cam lesion [26]), abnormal acetabular anteversion or excessive anterolateral acetabular bony rim coverage

(pincer lesion [26]), and combined cam-pincer lesions, FAI can lead to labral tears, cartilage delamination, and if untreated, osteoarthritis [9, 26, 43, 64]. With heightened awareness toward this clinical entity, FAI is being increasingly recognized in children and adolescents [66], who may present with hip pain exacerbated by athletic training or competition.

In 1936, Smith-Petersen described impingement in patients with proximal femoral deformities as a result of slipped capital femoral epiphysis (SCFE) and Legg-Calve-Perthes' disease and was the first to describe open surgical treatment with open acetabuloplasty through an anterior approach [69]. Later, after impingement had been proposed by Ganz et al. as a cause of osteoarthritis of the hip, surgical treatment of FAI in adults continued with open surgical dislocation via a novel transtrochanteric approach [26]. This involves performing a greater trochanteric osteotomy and osteoplasty of the femoral head-neck junction and acetabulum, thereby improving clearance for hip motion and alleviating femoral abutment against the acetabular rim [6, 37, 39, 46, 51, 54]. Since that time, combined open and arthroscopic approaches have been described [17]. In addition, for children with hip impingement, various osteotomies [19, 31, 70] have been used to correct femoral head-neck abnormalities to increase clearance between the femoral neck and acetabulum, although the focal impingement lesions were not necessarily altered.

Hip arthroscopy was described in the 1970s, but was not commonly used to treat the symptoms of FAI until the 1990s [10, 14]. In adults, this technique has been used with increasing frequency, largely based on studies reporting increases in functional outcome measures of up to 10 years [13, 14, 29, 38, 57], with complication rates less than 1.5% in several large series [11, 13, 15, 63]. Most complications are minor [15, 28, 63] (eg, chondral scuffing, temporary neurapraxia, broken instrumentation, fluid management, and undertreatment of hip disorders), with major complications (eg, femoral neck fracture, infection, iatrogenic instability and dislocation, abdominal compartment syndrome) being exceedingly rare [4, 24, 28, 48, 65]. Philippon et al. reported on 16 adolescent patients who underwent arthroscopy for FAI had improvements in a modified HHS, HOS—sport subset, and HOS—activity of daily living subset of 35, 56, and 36 points, respectively (all scores on a scale of 0–100) [59]. To our knowledge, this is the only published series on adolescents, and the study reports on skeletally immature patients who underwent only 'limited débridement' of osseous disorders, according to the authors' description [59].

Because it is not known how skeletally mature adolescent athletes respond to this treatment, we posed the following questions: (1) Do validated measures of hip function (HOS and modified HHS) improve after

arthroscopic treatment of FAI in a cohort of skeletally mature adolescent athletes? (2) What complications might be expected during and after arthroscopic treatment of FAI in these patients?

Patients and Methods

We retrospectively reviewed the records of all 21 athletically active patients 19 years of age or younger who underwent 27 hip arthroscopies for FAI from January 2007 to December 2008. We defined athletically active patients as those playing at least one organized sport or activity at school or in the community. We prospectively collected information regarding patient demographics, operative details, intraoperative or postoperative complications, and validated preoperative and postoperative modified HHS [12] and HOS [47] as part of an Institutional Review Board-approved hip arthroscopy patient registry. Because hip arthroscopy is principally indicated for pain and decreased function, these aspects of the HHS are maintained, whereas the section on ROM and deformity is eliminated in the modified version [12]. Of the total of 24 patients in this age range who underwent an arthroscopic hip procedure, we excluded three who underwent revision hip arthroscopy after having primary hip arthroscopy at another institution. This left 21 patients with 27 arthroscopies. Patients were an average of 17.6 years old (range, 14.5–19.9 years) at the time of surgery. Twelve of 21 patients were male and 15 of 27 procedures were performed on right hips. Six of 21 patients, all of whom were male, underwent staged bilateral procedures. Sports participation in patients varied widely with some patients playing multiple sports (Table 1). The minimum followup was 1 year (mean, 1.5 years; range, 1–2.5 years). No patients were lost to followup. No patients were recalled specifically for this study; all data were obtained from medical records.

Patients were indicated for arthroscopy based on clinical and radiographic signs and symptoms of FAI that were refractory to a minimum of 6 months of nonoperative treatment, which included activity modification, physical therapy, and steroid injections in the hip. Positive clinical examination findings included decreased internal rotation of the hip when flexed to 90° and a positive impingement sign [66]. Femoral version was assessed clinically. Plain-film evidence of FAI included decreased femoral head-neck offset (cam lesions) on the extended-leg lateral view [16] and crossover sign on AP radiographs of the pelvis (pincer lesions) [16, 62]. All patients underwent a diagnostic intraarticular anesthetic injection, which was associated with immediate considerable to complete relief of symptoms in all 21 patients during the immediate postinjection period, but which later proved to be transient.

For patients with signs and symptoms of concomitant internal snapping hip syndrome or psoas impingement syndrome [2, 3, 27, 30, 33], we performed separate diagnostic injections in the area of the iliopsoas bursa and a positive diagnosis applied to those with immediate considerable to complete relief of symptoms from the injection [1]. Chondral and labral disorders were evaluated using high-resolution, noncontrast MRI based on evidence from our institution regarding the equivalence or superiority to MR arthrograms for evaluation of labral disorders [50, 60] (Fig. 1), whereas bony pathoanatomy was assessed using plain radiographs and noncontrast CT scans with 3-D

reconstruction reformatted images (Fig. 2), based on emerging information regarding the value of CT for pre-operative planning [18]. We also used axial oblique imaging sequences in the CT scans to formally measure alpha angle [52], which was defined as positive for the presence of a cam lesion if the value was greater than 55° . Our contraindications for arthroscopic management of FAI include: acetabular dysplasia, posterior extension of impingement lesions which are poorly seen arthroscopically, acetabular retroversion with posterior wall deficiency, excessive femoral retroversion, and osteoarthritis greater than Tönnis Grade 1.

Table 1. Patient characteristics*

Variable	Value (frequency unless otherwise noted)	
Age	17.6 ± 1.6 years	
Gender		
Male	12	57%
Female	9	43%
Patients playing competitive sports	17	81%
Soccer	6	
Running	3	
Baseball/softball	3	
Ice hockey	3	
Football	2	
Basketball	2	
Lacrosse	2	
Swimming	1	
Tennis	1	
Rowing	1	
Patients playing recreational sports	4	19%

* 21 patients.

Fig. 1 A coronal proton density noncontrast MRI sequence shows a full-thickness degenerative labral tear at the site of impingement (triangle). The osseous cam deformity also is seen (arrow). * = hip capsule.

Fig. 2A–B Three-dimensional CT reconstructions show (A) an anteromedial oblique view of a right femoral neck cam lesion (arrow), and (B) a frontal view of a combined lesion in the left hip of another patient. Arrow = cam; * = pincer.

Table 2. Lesion characteristics*

Variable	Frequency	Percentage
Left	12	44%
Right	15	56%
Pincer	3	11%
Cam	5	19%
Combined	19	70%
Concomitant psoas releases	7	26%

* 27 hip arthroscopies.

All surgery was performed by one surgeon (BTK). Hip arthroscopy was performed with the patient in the supine position on a traction table under spinal anesthesia with intravenous sedation. We used a standard three-portal (anterolateral, posterolateral, anterior) technique along with variable use and position of a distal accessory portal, and all starting portals were placed under fluoroscopic guidance. T-shaped capsulotomies were performed with a Beaver blade on a long handle for increased observation and repaired with one or two simple capsular stitches before skin closure. Intraoperatively we observed various lesion characteristics (Table 2). We confirmed the presence of pincer lesions with meticulous inspection of the acetabulum, type of labral disorder, dynamic assessment of the impingement pattern with hip ROM with the traction released, and close correlation with the plain films and 3-D CT scans. We observed three types of labral disorders and each was treated accordingly: (1) erythematous contusion-type lesions in the anteroinferior labral region at approximately 3 o'clock (using the acetabular clock-face descriptive classification) [58] without obvious fraying were not specifically addressed, but were associated with psoas tendon impingement in all cases, therefore undergoing fractional psoas lengthening to decrease contact stresses at this anatomic intersection; (2) labral fraying was treated with limited débridement of only the frayed portions; and (3) in cases of frank detachment, the rim was decompressed directly using a 5.5-mm burr without primary detachment of the labrum. Areas where the labrum was deemed unstable or lacked adequate anchoring to deficient transition zone cartilage, suture refixation of the tissue was performed using intrasubstance passage of the suture resulting in anatomic restoration of a functional labral seal. We performed labral repairs in most cases with limited débridement where appropriate. In patients who had benefited from psoas injections, transcapsular assessment of the underside of the psoas tendon was performed arthroscopically and correlated with the status of the anterior labrum at approximately the 3 o'clock position (anteriorly as previously described [58]—3 o'clock on the

Fig. 3A–B Intraoperative fluoroscopy of cam decompression in the hip of a 19-year-old male is shown. **(A)** Before decompression, a cam lesion was identified (arrow). **(B)** After recontouring the femoral neck with a 3.5-mm arthroscopic burr, femoral head-neck offset was reestablished (arrow).

right acetabulum and reversed for the left acetabulum), where the psoas tendon passes over the acetabular rim. In patients with corresponding fraying or an erythematous, contusion-type lesion of the labrum, underside of psoas tendon, or both, we performed fractional release of the tendinous portion of the iliopsoas musculotendinous unit with a radiofrequency probe. After addressing all disorders in the central compartment, traction was released and a femoral head-neck osteoplasty for cam lesions was performed using an arthroscopic burr and fluoroscopic confirmation of adequacy of resection using AP, various frog-leg lateral, and dynamic views (Fig. 3).

Per an institutional protocol, pharmacologic deep venous thrombosis prophylaxis was deferred in this young healthy patient population. We encouraged patients to ambulate immediately with foot-flat touch-down (20%) weightbearing for 10 to 14 days wearing a hip abduction brace that allows for 0° to 70° flexion but blocks active abduction to prevent unintentional trauma or extreme ROM. Physical therapy is geared toward normalizing gait pattern using crutches, passive motion, isometrics, and hip extension. Patients then progress to weightbearing as tolerated between 2 and

4 weeks postoperatively. At this time patients begin core and hip strengthening exercises and progress with ROM exercises. They are seen in the office at 6 weeks to assess progress through physical therapy and radiographs including AP and elongated neck Dunn lateral views to confirm adequate postoperative correction of impingement disorders and absence of any postoperative heterotopic bone formation. Eight to 16 weeks postoperatively, patients begin endurance activities, plyometrics, and running. Patients begin sports-specific rehabilitation 3 months postoperatively and are cleared to return to athletics after 4 to 6 months depending on progress and any residual symptoms.

After the first 3 months, we reevaluated all patients at 6, 12, and 24 months postoperatively with repeat physical examination (impingement testing, manual muscle testing, pain evaluation, etc) and completion of the modified HHS and HOS instruments. Repeat radiographic imaging was performed 1 and 2 years postoperatively. The data were collected prospectively and analyzed retrospectively; there was only one missing data point throughout the study in the patient registry (postoperative HOS sport subset for one patient, HOS activity of daily living subset was filled out for this patient however).

Hip-specific descriptive statistics were calculated for clinical variables of interest. Preoperative to postoperative changes in modified HHS, HOS instruments, and self-reported hip function in the HOS sports subset were evaluated at the patient-level using the nonparametric Wilcoxon signed rank test (matched analysis of patients preoperative and postoperatively). All analyses were performed using SAS Software version 9.1 (SAS Institute, Cary, NC, USA). No sample size calculation was performed because this is a case series using all available subjects.

Results

The modified HHS improved by an average of 21 points, the activities of daily living subset of the HOS improved by

an average of 16 points, and the sports outcome subset of the HOS improved by an average of 33 points (Table 3). Self-reported hip function in the HOS sports subset improved with 19% reporting normal or nearly normal function preoperatively compared with 100% postoperatively ($p < 0.001$ for all measures). In hips that underwent head-neck osteochondroplasty (24 hips with five cam lesions and 19 combined lesions), the mean alpha angle improved from $64^\circ \pm 16^\circ$ to $40^\circ \pm 5.3^\circ$ postoperatively ($p \leq 0.001$ for all measures).

Patients who underwent labral refixation had improved modified HHS and HOS activity of daily living score by 27 and 20 points each compared with 19 points and 14 points respectively in patients who underwent labral débridement (Table 4). However, the final scores were similar for each group at the most recent followup: 85 versus 89 and 90 versus 93, respectively. Postoperative modified HHS, HOS activity of daily living, and HOS sport scores at the most recent followup for patients with psoas disorders who underwent a psoas release compared with those without psoas disorders were similar: 90 versus 87, 94 versus 92, and 89 versus 81, respectively. In patients who underwent psoas release, hip flexion strength measured by manual muscle testing normalized by the 6-month postoperative visit.

There were no intraoperative or postoperative complications in this series of patients.

Discussion

Arthroscopic treatment of FAI is becoming more popular as reports of improvements in hip-specific outcome scores (eg, HHS, HOS) at 2 to 10 years are favorable [13, 14, 29, 38, 57], with complication rates less than 1.5% in several large adult series [11, 13, 15, 63]. Without similar reports for children and adolescents, the use of arthroscopy in this cohort is unfounded. Because it is not known how skeletally mature adolescent athletes respond to this treatment, we posed the following questions: (1) Do validated

Table 3. Preoperative and postoperative outcomes measures

Measure	Number	Mean preoperative value			Mean postoperative value			Mean improvement	Significance
Modified Harris hip score	21	67			88			21	$p < 0.001$
Hip Outcome Score									
Activities of daily living	21	77			92			16	$p < 0.001$
Sport	20*	49			82			33	$p = 0.001$
Self-reported hip outcome	21	Normal	1	3.7%	Normal	7	37.0%		
Score – sport function		Nearly normal	4	14.8%	Nearly normal	14	63.0%		$p < 0.001$
		Abnormal	14	70.4%	Abnormal	0	0.0%		
		Severely abnormal	2	11.1%	Severely abnormal	0	0.0%		

* One patient did not complete the sports section for the postoperative HOS.

Table 4. Interval improvement in outcome measures stratified by additional treatments

Outcome measure	Mean interval improvement in score			
	Psoas disorder (scaled improvement)		Labral repair (scaled improvement)	
	Yes (n = 6)	No (n = 15)	Yes (n = 5)	No (n = 16)
Modified Harris hip score	28	15	27	19
Hip Outcome Score				
Activities of daily living	18	15	20	14
Sport	50	27	39	32

All means improved positively between preoperative and postoperative period.

measures of hip function (HOS and modified HHS) improve after arthroscopic treatment of FAI in a cohort of skeletally mature adolescent athletes? (2) What complications might be expected during and after arthroscopic treatment of FAI in these patients?

There are several limitations to the study, including a relatively small sample size, which precluded extensive statistical analysis of specific demographic and treatment factors that might have been associated with improved hip scores. Hip arthroscopy in this demographic (specifically, adolescent athletes), however, is rare, thereby precluding formal multivariate analysis. Instead, we analyzed the results of this unique cohort as a whole. In addition, our followup interval averaged 1.5 years, and longer-term data are needed to determine whether the early benefits are maintained and whether there is a potential to reduce the risk or delay the onset of OA. Finally, this was a retrospective study. However despite a retrospective statistical analysis, data were collected prospectively in a surgical patient registry, thus eliminating loss of patients to followup.

Several studies have described arthroscopic treatment of adult patients with FAI [13, 29, 38, 57]; the adolescent population in the current study benefited from similar improvements in modified HHS, HOS activity of daily living score, and HOS sport score, with improvements of 21, 16, and 33 points, respectively. These scores are comparable to previously reported improvements of 20 to 30 points on the modified HHS, 15 to 30 points on the HOS activity of daily living score, and 25 to 35 points on the HOS sport score in major adult series [13, 29, 38, 57] (Table 5). There have been few studies investigating hip arthroscopy in children [7, 35, 36, 59, 67, 71]. Kocher et al. evaluated 54 hip arthroscopies in 42 patients younger than 18 years with a minimum of 1 year followup [35]. Surgical indications included labral tear, Perthes disease, inflammatory arthritis, spondyloepiphyseal dysplasia, and avascular necrosis, among others. They reported improvement in 83% of patients with modified HHS improvements of 30 points on

average. Excluding recurrent labral tears, only four complications were noted: transient pudendal nerve palsies (three) and broken instrumentation (one). However, no patients in their series were indicated specifically for treatment of FAI. In contrast, in the current series, we used FAI as the primary surgical indication as defined by the previously mentioned clinical and radiographic diagnostic criteria. Philippon et al. reported clinical improvements in pain and function as measured using modified HHS and HOS instruments after hip arthroscopy for treatment of FAI in a similar cohort of active adolescents [59]. Unlike their series, however, no adolescents in our study were skeletally immature at the time of surgery. Therefore, complete head-neck osteoplasties were performed for cam lesions rather than the limited osteoplasties they describe to avoid potential physeal damage. Fifty percent of patients in their series also underwent capsular plication for hip instability, whereas this procedure was not performed on any patient in our series. Although some reviews [8, 55, 56, 61, 68] have described hip instability as a rare but reasonable indication for arthroscopic techniques, we are not aware of any data detailing the effectiveness of arthroscopic plication of the hip capsule or of any specific association between FAI and hip instability. Another difference is that some patients in the current series (26%) were diagnosed, based on clinical and arthroscopic criteria, to have a concurrent psoas disorder warranting fractional release of the psoas tendon. Philippon et al. described no interventions for psoas disorders [59].

In our series and that of Philippon et al. [59], a combination of labral débridement and refixation was performed. Some efforts have been focused on preserving and repairing labral tissue whenever possible. Biomechanical studies have indicated that intact labral tissue supports natural joint lubrication and the presence of a 'suction seal' that limits translation and instability [21–23, 34]. Espinosa et al. reported patients treated with labral refixation rather than débridement had superior clinical and radiographic improvements as measured by the Tönnis arthrosis classification system and Merle d'Aubigné-Postel clinical score at 1 and

Table 5. Studies investigating clinical improvement after arthroscopic treatment of FAI*

Study	Patient age (years) [†]	Number of hips	Limited/full osteoplasty	Followup interval (years) [†]	Complication rate	Modified HHS	Improvements in clinical outcome scores	
							HOS—ADL	HOS—Sport
Adult								
Byrd & Jones [12]	33	207	Full	1.3 [1, 2]	1.5%	20	—	—
Larson & Giveans [38]	34.7 [16–64]	100	Full	0.8 [0.25–3]	8%, minor, all resolved	22	—	—
Philippon et al. [57]	40.6 [37–43]	122	Full	2.3 [2–2.9]	0%	24	17	24
Pediatric/adolescent								
Philippon et al. [59]	15 [11–16]	16	Limited	1.36 [1–2]	0%	35	36	56
Current study	17 [14–19]	27	Full	1.5 [1–2.5]	0%	21	16	33

* Cam, pincer, and combined lesions included; [†]average and range, if provided; HHS = Harris hip score; HOS = Hip Outcome Score; ADL = activities of daily living.

2 years postoperatively [20]. This was confirmed by Philippon et al. who noted the postoperative modified HHS was better at an average of 2.3 years in adults who underwent labral fixation instead of débridement during hip arthroscopy to treat FAI [57]. Despite trends toward greater improvements in the modified HHS and HOS activity of daily living score after labral refixation in this adolescent cohort (Table 4), the limited sample size precluded statistical evaluation of this variable as a predictor of improved clinical outcome scores. Larger prospective series are required to determine if maintaining a suction seal through labral fixation instead of débridement helps improve clinical outcome scores in this population, but in the absence of definitive evidence to the contrary, repairing the labrum whenever possible may be important in maintaining the normal anatomy of the hip and slowing the natural history of degenerative hip disease. Further prospective and long-term outcome data are needed to determine if there are any specific clinical and demographic predictors of short- and long-term outcome in adolescents.

Several studies have reported low complication rates in adults [14, 15, 28], and we found the same in our adolescent cohort, in which no complications were seen.

We observed improvements in the modified HHS, HOS activity of daily living score, and HOS sport score of 21, 16, and 33 points, respectively, with no intraoperative or postoperative complications. Although these early data substantiate the use of hip arthroscopy as surgical management of FAI in adolescent athletes, long-term prospective research is needed to determine whether these early benefits are maintained and whether there is a potential to reduce the risk or delay the onset of OA.

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References

- Adler RS, Buly R, Ambrose R, Sculco T. Diagnostic and therapeutic use of sonography-guided iliopsoas peritendinous injections. *AJR Am J Roentgenol*. 2005;85:940–943.
- Alpert JM, Kozanek M, Li G, Kelly BT, Asnis PD. Cross-sectional analysis of the iliopsoas tendon and its relationship to the acetabular labrum: an anatomic study. *Am J Sports Med*. 2009;37:1594–1598.
- Anderson SA, Keene JS. Results of arthroscopic iliopsoas tendon release in competitive and recreational athletes. *Am J Sports Med*. 2008;36:2363–2371.
- Bartlett CS, DiFelice GS, Buly RL, Quinn TJ, Green DS, Helfet DL. Cardiac arrest as a result of intraabdominal extravasation of fluid during arthroscopic removal of a loose body from the hip joint of a patient with an acetabular fracture. *J Orthop Trauma*. 1998;12:294–299.
- Beck M, Kalhor M, Leunig M, Ganz R. Hip morphology influences the pattern of damage to the acetabular cartilage: femoroacetabular impingement as a cause of early osteoarthritis of the hip. *J Bone Joint Surg Br*. 2005;87:1012–1018.
- Beck M, Leunig M, Parvizi J, Boutier V, Wyss D, Ganz R. Anterior femoroacetabular impingement: Part II. Midterm results of surgical treatment. *Clin Orthop Relat Res*. 2004;418:67–73.
- Berend KR, Vail TP. Hip arthroscopy in the adolescent and pediatric athlete. *Clin Sports Med*. 2001;20:763–778.
- Boykin RE, Anz AW, Bushnell BD, Kocher MS, Stubbs AJ, Philippon MJ. Hip instability. *J Am Acad Orthop Surg*. 2011; 19:340–349.
- Byers PD, Contepomi CA, Farkas TA. A post mortem study of the hip joint: including the prevalence of the features of the right side. *Ann Rheum Dis*. 1970;29:15–31.
- Byrd JW. Hip arthroscopy utilizing the supine position. *Arthroscopy*. 1994;10:275–280.
- Byrd JW, ed. *Operative Hip Arthroscopy*. New York, NY: Thieme; 1998.
- Byrd JW, Jones KS. Prospective analysis of hip arthroscopy with 2-year follow-up. *Arthroscopy*. 2000;16:578–587.
- Byrd JW, Jones KS. Arthroscopic femoroplasty in the management of cam-type femoroacetabular impingement. *Clin Orthop Relat Res*. 2009;467:739–746.
- Byrd JW, Jones KS. Prospective analysis of hip arthroscopy with 10-year followup. *Clin Orthop Relat Res*. 2010;468:741–746.

15. Clarke MT, Arora A, Villar RN. Hip arthroscopy: complications in 1054 cases. *Clin Orthop Relat Res.* 2003;406:84–88.
16. Clohisy JC, Carlisle JC, Beaulé PE, Kim YJ, Trousdale RT, Sierra RJ, Leunig M, Schoenecker PL, Millis MB. A systematic approach to the plain radiographic evaluation of the young adult hip. *J Bone Joint Surg Am.* 2008;90(suppl 4):47–66.
17. Clohisy JC, Zebala LP, Nepple JJ, Pashos G. Combined hip arthroscopy and limited open osteochondroplasty for anterior femoroacetabular impingement. *J Bone Joint Surg Am.* 2010;92:1697–1706.
18. Dolan MM, Heyworth BE, Bedi A, Duke G, Kelly BT. CT reveals a high incidence of osseous abnormalities in hips with labral tears. *Clin Orthop Relat Res.* 2011;469:831–838.
19. Dunn DM. The treatment of adolescent slipping of the upper femoral epiphysis. *J Bone Joint Surg Br.* 1964;46:621–629.
20. Espinosa N, Rothenfluh DA, Beck M, Ganz R, Leunig M. Treatment of femoro-acetabular impingement: preliminary results of labral refixation. *J Bone Joint Surg Am.* 2006;88:925–935.
21. Ferguson SJ, Bryant JT, Ganz R, Ito K. The acetabular labrum seal: a poroelastic finite element model. *Clin Biomech (Bristol, Avon).* 2000;15:463–468.
22. Ferguson SJ, Bryant JT, Ganz R, Ito K. The influence of the acetabular labrum on hip joint cartilage consolidation: a poroelastic finite element model. *J Biomech.* 2000;33:953–960.
23. Ferguson SJ, Bryant JT, Ganz R, Ito K. An in vitro investigation of the acetabular labral seal in hip joint mechanics. *J Biomech.* 2003;36:171–178.
24. Fowler J, Owens BD. Abdominal compartment syndrome after hip arthroscopy. *Arthroscopy.* 2010;26:128–130.
25. Ganz R, Leunig M, Leunig-Ganz K, Harris WH. The etiology of osteoarthritis of the hip: an integrated mechanical concept. *Clin Orthop Relat Res.* 2008;466:264–272.
26. Ganz R, Parvizi J, Beck M, Leunig M, Notzli H, Siebenrock KA. Femoroacetabular impingement: a cause for osteoarthritis of the hip. *Clin Orthop Relat Res.* 2003;417:112–120.
27. Heyworth BE, Shindle MK, Voos JE, Rudzki JR, Kelly BT. Radiologic and intraoperative findings in revision hip arthroscopy. *Arthroscopy.* 2007;23:1295–1302.
28. Ilizaliturri VM Jr. Complications of arthroscopic femoroacetabular impingement treatment: a review. *Clin Orthop Relat Res.* 2009;467:760–768.
29. Ilizaliturri VM Jr, Orozco-Rodriguez L, Acosta-Rodriguez E, Camacho-Galindo J. Arthroscopic treatment of cam-type femoroacetabular impingement: preliminary report at 2 years minimum follow-up. *J Arthroplasty.* 2008;23:226–234.
30. Ilizaliturri VM Jr, Villalobos FE Jr, Chaidez PA, Valero FS, Aguilera JM. Internal snapping hip syndrome: treatment by endoscopic release of the iliopsoas tendon. *Arthroscopy.* 2005;21:1375–1380.
31. Imhauser G. [Late results of Imhauser's osteotomy for slipped capital femoral epiphysis (author's transl)] [in German]. *Z Orthop Ihre Grenzgeb.* 1977;115:716–725.
32. Ito K, Leunig M, Ganz R. Histopathologic features of the acetabular labrum in femoroacetabular impingement. *Clin Orthop Relat Res.* 2004;429:262–271.
33. Kelly BT, Philippon MJ. Arthroscopic hip anatomy. In: Callaghan JJ, Rosenberg AG, Rubash HE, eds. *The Adult Hip*. Ed 2. Philadelphia, PA: Lippincott Williams & Wilkins; 2007: 68.
34. Kelly BT, Williams RJ 3rd, Philippon MJ. Hip arthroscopy: current indications, treatment options, and management issues. *Am J Sports Med.* 2003;31:1020–1037.
35. Kocher MS, Kim YJ, Millis MB, Mandiga R, Siparsky P, Micheli LJ, Kasser JR. Hip arthroscopy in children and adolescents. *J Pediatr Orthop.* 2005;25:680–686.
36. Kocher MS, Tucker R. Pediatric athlete hip disorders. *Clin Sports Med.* 2006;25:241–253, viii.
37. Kohnlein W, Ganz R, Impellizzeri FM, Leunig M. Acetabular morphology: implications for joint-preserving surgery. *Clin Orthop Relat Res.* 2009;467:682–691.
38. Larson CM, Giveans MR. Arthroscopic management of femoroacetabular impingement: early outcomes measures. *Arthroscopy.* 2008;24:540–546.
39. Lavigne M, Parvizi J, Beck M, Siebenrock KA, Ganz R, Leunig M. Anterior femoroacetabular impingement: Part I. Techniques of joint preserving surgery. *Clin Orthop Relat Res.* 2004;418:61–66.
40. Leunig M, Beaulé PE, Ganz R. The concept of femoroacetabular impingement: current status and future perspectives. *Clin Orthop Relat Res.* 2009;467:616–622.
41. Leunig M, Beck M, Dora C, Ganz R. [Femoroacetabular impingement: trigger for the development of coxarthrosis] [in German]. *Orthopade.* 2006;35:77–84.
42. Leunig M, Beck M, Kalhor M, Kim YJ, Werlen S, Ganz R. Fibrocystic changes at anterosuperior femoral neck: prevalence in hips with femoroacetabular impingement. *Radiology.* 2005;236:237–246.
43. Leunig M, Beck M, Woo A, Dora C, Kerboull M, Ganz R. Acetabular rim degeneration: a constant finding in the aged hip. *Clin Orthop Relat Res.* 2003;413:201–207.
44. Leunig M, Ganz R. [Femoroacetabular impingement: a common cause of hip complaints leading to arthrosis] [in German]. *Unfallchirurg.* 2005;108:9–10, 12–17.
45. Leunig M, Ganz R. [FAI: concept and etiology] [in German]. *Orthopade.* 2009;38:394–401.
46. Leunig M, Huff TW, Ganz R. Femoroacetabular impingement: treatment of the acetabular side. *Instr Course Lect.* 2009;58:223–229.
47. Martin RL, Philippon MJ. Evidence of reliability and responsiveness for the hip outcome score. *Arthroscopy.* 2008;24:676–682.
48. Matsuda DK. Acute iatrogenic dislocation following hip impingement arthroscopic surgery. *Arthroscopy.* 2009;25:400–404.
49. Meyer DC, Beck M, Ellis T, Ganz R, Leunig M. Comparison of six radiographic projections to assess femoral head/neck asphericity. *Clin Orthop Relat Res.* 2006;445:181–185.
50. Mintz DN, Hooper T, Connell D, Buly R, Padgett DE, Potter HG. Magnetic resonance imaging of the hip: detection of labral and chondral abnormalities using noncontrast imaging. *Arthroscopy.* 2005;21:385–393.
51. Murphy S, Tannast M, Kim YJ, Buly R, Millis MB. Debridement of the adult hip for femoroacetabular impingement: indications and preliminary clinical results. *Clin Orthop Relat Res.* 2004; 429:178–181.
52. Notzli HP, Wyss TF, Stoecklin CH, Schmid MR, Treiber K, Hodler J. The contour of the femoral head-neck junction as a predictor for the risk of anterior impingement. *J Bone Joint Surg Br.* 2002;84:556–560.
53. Parvizi J, Leunig M, Ganz R. Femoroacetabular impingement. *J Am Acad Orthop Surg.* 2007;15:561–570.
54. Peters CL, Erickson JA. Treatment of femoro-acetabular impingement with surgical dislocation and debridement in young adults. *J Bone Joint Surg Am.* 2006;88:1735–1741.
55. Philippon MJ. The role of arthroscopic thermal capsulorrhaphy in the hip. *Clin Sports Med.* 2001;20:817–829.
56. Philippon MJ. New frontiers in hip arthroscopy: the role of arthroscopic hip labral repair and capsulorrhaphy in the treatment of hip disorders. *Instr Course Lect.* 2006;55:309–316.
57. Philippon MJ, Briggs KK, Yen YM, Kuppersmith DA. Outcomes following hip arthroscopy for femoroacetabular impingement with associated chondrolabral dysfunction: minimum two-year follow-up. *J Bone Joint Surg Br.* 2009;91:16–23.

58. Philippon MJ, Stubbs AJ, Schenker ML, Maxwell RB, Ganz R, Leunig M. Arthroscopic management of femoroacetabular impingement: osteoplasty technique and literature review. *Am J Sports Med.* 2007;35:1571–1580.
59. Philippon MJ, Yen YM, Briggs KK, Kuppersmith DA, Maxwell RB. Early outcomes after hip arthroscopy for femoroacetabular impingement in the athletic adolescent patient: a preliminary report. *J Pediatr Orthop.* 2008;28:705–710.
60. Potter HG, Schachar J. High resolution noncontrast MRI of the hip. *J Magn Reson Imaging.* 2010;31:268–278.
61. Ranawat AS, McClincy M, Sekiya JK. Anterior dislocation of the hip after arthroscopy in a patient with capsular laxity of the hip: a case report. *J Bone Joint Surg Am.* 2009;91:192–197.
62. Reynolds D, Lucas J, Klaue K. Retroversion of the acetabulum: a cause of hip pain. *J Bone Joint Surg Br.* 1999;81:281–288.
63. Sampson TG. Complications of hip arthroscopy. *Clin Sports Med.* 2001;20:831–835.
64. Seldes RM, Tan V, Hunt J, Katz M, Winiarsky R, Fitzgerald RH Jr. Anatomy, histologic features, and vascularity of the adult acetabular labrum. *Clin Orthop Relat Res.* 2001;382:232–240.
65. Sharma A, Sachdev H, Gomillion M. Abdominal compartment syndrome during hip arthroscopy. *Anaesthesia.* 2009;64:567–569.
66. Sink EL, Gralla J, Ryba A, Dayton M. Clinical presentation of femoroacetabular impingement in adolescents. *J Pediatr Orthop.* 2008;28:806–811.
67. Siparsky PN, Kocher MS. Current concepts in pediatric and adolescent arthroscopy. *Arthroscopy.* 2009;25:1453–1469.
68. Smith MV, Sekiya JK. Hip instability. *Sports Med Arthrosc.* 2010;18:108–112.
69. Smith-Petersen MN. Treatment of malum coxae senilis, old slipped upper femoral epiphysis, intrapelvic protrusion of the acetabulum, and coxa plana by means of acetabuloplasty. *J Bone Joint Surg Am.* 1936;18:869–880.
70. Southwick WO. Osteotomy through the lesser trochanter for slipped capital femoral epiphysis. *J Bone Joint Surg Am.* 1967;48:807–835.
71. Yen YM, Kocher MS. Chondral lesions of the hip: microfracture and chondroplasty. *Sports Med Arthrosc.* 2010;18:83–89.