Journal of Hip Preservation Surgery Vol. 6, No. 1, pp. 16–24
doi: 10.1093/jhps/hnz010
Advance Access Publication 15 March 2019
Research article

OXFORD

Is there a correlation between outcomes after hip arthroscopy for femoroacetabular impingement syndrome and patient cortical bone thickness?

Edward C. Beck [1], Kyle N. Kunze [1], Nicole A. Friel[2], William H. Neal[2], Michael C. Fu[3], Brian D. Giordano[4], Jorge Chahla[1] and Shane J. Nho[1]*

[1]Section of Young Adult Hip Surgery, Division of Sports Medicine, Department of Orthopedic Surgery, Rush University Medical Center, 1611 West Harrison Street, Suite 300, Chicago, IL 60612, USA,
[2]Department of Orthopaedic Surgery, Shriner's Hospital for Children, Sacramento, CA, USA,
[3]Department of Orthopaedic Surgery, Hospital for Special Surgery, New York, NY, USA and
[4]Department of Orthopaedic Surgery, University of Rochester Medical Center, Rochester, NY, USA.
*Correspondence to: S. J. Nho. E-mail: shane.nho@rushortho.com **or** nho.research@rushortho.com
Submitted 22 October 2018; Revised 1 January 2019; revised version accepted 3 February 2019

ABSTRACT

In order to determine the associations between age, sex, cortical bone thickness (CBT), and outcomes following hip arthroscopy for FAIS, a retrospective study of patients undergoing hip arthroscopy for FAIS from a single institution from 2012 to 2014 was performed. Based on preoperative radiographs, femoral cortical index (FCI) and femoral canal-to-calcar ratio (FCC) were used as measures of CBT and used to classify patients using the Dorr classification. Linear and logistic regression was used to determine whether CBT was predictive of 2-year patient reported outoutcomes. Patients were stratified by sex and age (<45 or =45 years old) to determine whether variables were potential effect modifiers on the association between outcomes and CBT. A total of 108 patients were included in the study, with 27 patients in each of the following groups: females <45, females =45, males <45, and males =45 years. The results showed that at 2-year follow-up, all groups demonstrated significant improvements in reported outcomes (HOS-ADL, HOS-SS, and mHHS) ($p<0.001$). Females =45 scored significantly worse than other groups on all scores ($p<0.05$ for all). Chi-square test for trend showed a linear by linear association between Dorr classification type and gender/age group ($p=0.018$). Analysis of the whole study population showed a linear association between FCC and HOS-ADL and mHHS scores. However, CBT measures were not predictive of achieving MCID. In conclusion, patients undergoing hip arthroscopy for FAIS, older female patients had the worst patient-reported outcomes and lowest CBT measures. Furthermore, FCC is independently associated with the HOS-ADL and mHHS.

LEVEL OF EVIDENCE: Retrospective comparative study, Level III

What is known about the subject: Among patients undergoing hip arthroscopy for FAIS, female patients over the age of 45 have been reported to be at risk for inferior post-operative outcomes. Meanwhile, this patient population is also the most at risk for deteriorating CBT.

What this study adds to existing knowledge: This study demonstrates that female patients with FAIS over the age of 45 have inferior CBT indices than their male and younger-aged counterparts. Furthermore, this study presents an association between the FCC and 2-year patient-reported outcome measures, suggesting that CBT characterization may withhold prognostic value.

INTRODUCTION

Femoroacetabular impingement syndrome (FAIS), characterized by abnormal contact between the femoral head-neck junction and the acetabular rim, is an increasingly recognized source of hip pain and dysfunction. Concurrently, hip arthroscopy has been adopted as a safe and minimally invasive approach for treating FAIS, with excellent outcomes [1]. The contemporary treatment of FAIS consists of chondrolabral repair if necessary, surgical correction of underlying bony pathomorphology and capsular repair or plication.

Although most patients undergoing hip arthroscopy for FAIS demonstrate significant improvements in patient-reported outcomes (PROs), certain subsets of patients may be at risk of inferior results. For example, Frank *et al.* [2] reported that patients older than 45 years of age, and particularly females older than 45, had significantly worse outcomes than patients younger than 45. In addition to the association between lower PROs and decreased joint space and older age, other potential concomitant risk factors among older females may be low bone mineral density (BMD), and osteoporosis. With increasing age, a confluence of metabolic and hormonal changes, diet and exercise leads to loss in BMD [3]. In particular, there appears to be a synergistic effect between sex and aging on the development of osteoporosis, as it is estimated that there are currently 9.1 million women with osteoporosis and an additional 26 million with osteopenia, while there are currently only 2.8 million men with osteoporosis and an additional 14.4 million with osteopenia [4]. Women also have higher fracture risks than men, as the lifetime risk of a woman aged 60 is nearly double (44 versus 25%) that of an age-matched male [5].

In terms of assessing BMD, dual energy X-ray absorptiometry (DEXA) is the commonly used standard to diagnose osteoporosis and to monitor the effect of treatment [6]. DEXA does have a number of limitations, however, such as prognostic ability to predict risk of fracture and subjectivity in interpretation [7–9]. Most importantly, it is not routinely obtained in younger patients, such as those undergoing hip arthroscopy. As such, recent studies have aimed to validate alternative means of BMD assessment, using plain radiographs of the hip. The Dorr classification system is one such model developed from radiographic classifications of bone quality which were validated with histological findings. This system uses plain films to estimate proximal femur BMD based on cortical bone thickness (CBT) and the local anatomy of the femoral canal and calcar (FCC). This method has been used in subsequent studies and shown to have strong correlations with osteoporosis when compared against DEXA scans [6, 10–12].

Although the effect of CBT on post-operative survival and outcomes after hip arthroplasty [13] and spine surgery [14, 15] have been studied extensively, the relationships between CBT, age and sex among patients undergoing hip arthroscopy for FAIS are not completely understood. Therefore, the purpose of this study was to evaluate the effect of CBT, as measured on plain radiographs typically available as part of standard pre-operative work-up, on PROs following hip arthroscopy for the treatment of FAIS. We hypothesized that decreased CBT would be associated with inferior post-operative outcomes, and that older female patients with FAIS would have the lowest CBT.

MATERIALS AND METHODS

A retrospective review of our institution's prospectively recorded surgical registry revealed 592 patients who underwent arthroscopic surgery for FAIS between January 2012 and 2014. All surgeries were performed by a single fellowship-trained surgeon. No funding was received and institutional review board approval was obtained prior to the beginning of the study.

Patient selection

Inclusion criteria consisted of patients with FAIS that underwent primary hip arthroscopy after failed non-operative treatment (activity modification, oral anti-inflammatories, cortisone injections and/or physical therapy). Pre-operatively, these patients had correlating history, impingement signs on exam and radiographic evidence (e.g. pistol grip deformity, crossover sign, alpha angle $>55^\circ$ on cross-table plain radiograph) indicative of FAIS. Exclusion criteria were advanced hip osteoarthritis (Tonnis Grade >2), hip dysplasia (lateral center edge angle $<20^\circ$), neurodegenerative diseases, patients undergoing revision hip arthroscopy, ASA level >2, history of previous hip surgery bilaterally, history of spine surgery and concomitant hip procedures (e.g. bursitis, gluteus tear repair etc.) during the time of arthroscopy. Patients were stratified into four groups based on age and sex: (i) males <45, (ii) females <45, (iii) males ≥45 and (iv) females ≥45.

Surgical technique

The surgical technique performed was similar to what has been previously described [16, 17] which incorporates labral repair or labral debridement, femoral osteochondroplasty, acetabular rim trimming and complete capsular closure. All surgeries were performed with the patient in the supine position on a standard traction table under general anesthesia. Anterolateral and mid-anterior portals were created to establish visualization into the central compartment and a T-capsulotomy was performed for visualization of the peripheral compartment. Closure of the capsulotomy via repair of the interportal and T-capsulotomy incisions was performed in all cases. Hip traction was released immediately after work was concluded in the central compartment, and a dynamic examination was then performed to confirm resolution of impingement. Labral refixation was performed when gross detachment of the labrum from the acetabular rim was observed; otherwise, a partial debridement was used for patients with sufficient labral tissue with little or no detachment.

Post-operative rehabilitation

Rehabilitation started on post-operative day 1 for all patients as previously described [18, 19]. Patients went through a four-phase rehabilitation protocol that lasted an average of 16–18 weeks. Rehabilitation Phase 1 prioritized joint protection and soft tissue mobilization techniques. Phase 2 focused on the re-establishment of normal gait maintenance, full range of motion, improvement of neuromuscular control and maintenance of pelvic and core stability. Phase 3 included single leg squats and strengthening, soft tissue and joint mobilization and cardiovascular fitness. Phase 4 emphasized return to pre-injury level of sports participation. Patients were cleared to return to sports if they were able to participate in sports without pain, had full dynamic functional control and passed all return to sports tests.

Functional outcome evaluation

All patients completed the patient-determined visual analog scale (VAS) for pain and satisfaction, as well as hip-specific outcome instruments including the Hip Outcome Score-Activities of Daily Living (HOS-ADL) [20] and Sports-Specific Subscale (HOS-SS) [21], as well as the modified Harris Hip Score (mHHS) [22, 23] pre-operatively and at 6 months, 1 year and a minimum of 2-years after surgery. Superior clinical outcome was defined as reaching MCID for HOS-ADL, HOS-SS and mHHS at 2 years post-operatively. In same fashion described previously in the literature, MCID was determined by calculating the $\frac{1}{2}$ standard deviation of the HOS-ADL average in the study patients [24–26]. The MCID was calculated to be 10.7, 17.0 and 9.6, respectively.

Radiographic analysis

Pre-operative anteroposterior (AP) pelvis, false profile and Dunn lateral radiographs were obtained in the supine position. The joint space width, lateral center-edge angle of Wiberg (AP view) and alpha angle (Dunn lateral view) were measured as part of the pre-operative assessment [27]. Pre-operative magnetic resonance imaging or computed tomography (CT) assessed chondrolabral pathology and osseous morphology. All measurements were by made by the senior author with a picture archiving communication system. The analysis was performed post-operatively, so that all patients from this time period had a minimum of 2-year outcomes. Pre-operative X-rays taken at the visit prior to surgery were used to evaluate CBT.

CBT analysis

The aforementioned Dorr classification was used to assess CBT from pre-operative radiographs [6, 28]. Proximal femur bony morphology was categorized into three types, with Type A having thick cortices and a narrow funnel-shaped femoral canal, Type B having thinner medial and posterior cortices and irregular endosteal surfaces and Type C with the thinnest medial and posterior cortices and a cylindrical appearance (Fig. 1). One trained observer made the CBT measurements under the supervision of an attending orthopedic surgeon and radiologist. Twenty subsequent measurements on random radiographs were performed in order to assess intra-rater reliability for these measurements. The intra-observer reliability for this aspect was calculated to be 0.90 (95% CI 0.84–0.93).

The cortical thickness index, or femoral cortical index (FCI), was measured on AP radiographs according to Dorr *et al.* [6, 28]. Cortical thickness was measured at a point 10 cm distal to the lesser trochanter (Fig. 2). Cortical thickness index was calculated as the ratio of the femoral diaphysis width (DW) minus medullary canal width (FW) divided by femoral diaphysis width (Cortical Index = [DW − FW]/DW). A high cortical index signifies greater thickness as well as greater bone density [6]. FCC ratio was also measured on an AP plain radiograph. The canal to calcar ratio (CC) was calculated as the fraction of the isthmus canal width (FW) divided by the calcar canal dimension (CW). A high FCC ratio indicates inferior BMD [6, 28]. The intra-observer reliability was calculated to be 0.92 (95% CI = 0.87–0.94).

Statistical analysis

Descriptive statistics were calculated for continuous variables as means and standard deviations and percentages where appropriate. Pre- and post-operative outcomes scores, as well as CBT, were compared between cohorts using independent *t*-tests. Chi-squared analysis was used as appropriate to compare categorical variables between groups. Linear regression determined associations between CBT measures (Dorr classification type, FCC and FCI) and post-operative outcome scores. Logistic regression was used to determine whether CBT measures were predictive of achieving the MCID for the HOS-ADL, HOS-SS or

Fig. 1. Examples of the Door classification used to assess CBT from pre-operative radiographs. Type A has thick cortices and a narrow funnel-shaped femoral canal, Type B has thinner medial and posterior cortices and irregular endosteal surfaces and Type C has the thinnest medial and posterior cortices and a cylindrical appearance.

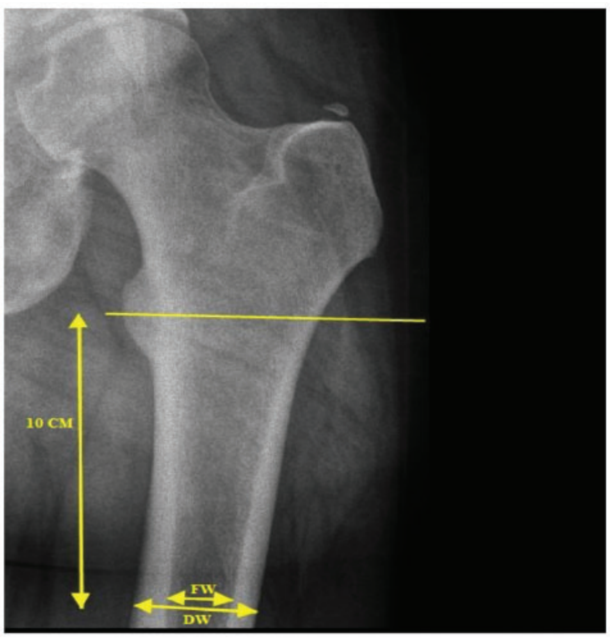

Fig. 2. Measurement of cortical thickness. In order to ensure consistency, cortical thickness was measured at a point 10 cm distal to the lesser trochanter, for every pre-operative radiograph. Cortical thickness index was calculated as the ratio of the femoral diaphysis width (DW) minus medullary canal width (FW) divided by femoral diaphysis width (Cortical Index = [DW−FW]/DW).

Table I. Demographics of all patients

	Mean ± SD
Follow-up	32.9 ± 9.3
Age	40.9 + 13.1
BMI	26.1 ± 4.4

mHHS. An *a priori* power analysis was performed to determine the minimum sample size required to overcome Type II error. Based on the study population of previous sports surgery studies analyzing the effect of age and gender on clinical outcome scores [2], the minimum sample size per group for a two-tailed *t*-test study was 27. A *P* value of < 0.05 was used as the level of statistical significance. Data analysis was performed using SPSS statistical software (IBM SPSS Statistics for MacOS, Version 25.0. Armonk, NY: IBM).

RESULTS

Following application of inclusion and exclusion criteria, a total of 108 patients, with a mean follow-up time of 32.9 ± 9.3 months. The whole patient study group had an average age of 40.9 + 13.1 years, and a BMI of 26.1 ± 4.4 kg/m^2 (Table I). Analysis of PROs demonstrated a statistically

Table II. Analysis of pre- versus post-operative PROs

	Pre-operative	*Post-operative*	*P-value*
HOS-ADL	64.8 ± 19.9	85.7 ± 18.7	<0.001
HOS-SS	40.1 ± 26.6	73.4 ± 28.6	<0.001
mHHS	58.3 ± 16.9	77.1 ± 18.3	<0.001
VAS pain	75.9 ± 14.7	19.1 ± 24.6	<0.001
VAS satisfaction	—	87.4 ± 38.3	

Table III. Linear regression models for associations between CBT indices and reported outcomes

	Beta	*SE*	*P-value*
HOS-ADL			
FCC	–0.248	18.477	**0.01**
FCI	0.182	25.11	0.059
Dorr type	–0.148	3.089	0.125
HOS-SS			
FCC	–0.222	29.296	**0.028**
FCI	0.18	40.929	0.074
Dorr type	–0.127	5.005	0.209
mHHS			
FCC	–0.225	17.585	**0.019**
FCI	0.103	24.037	0.288
Dorr type	–0.169	2.913	0.08
VAS Pain			
FCC	0.08	23.685	0.418
FCI	0.001	31.884	0.994
Dorr type	0.028	3.893	0.781

Bold value indicate statistical significance (p-value<0.05).

significant improvement in HOS-ADL (64.8 ± 19.9 versus 85.7 ± 18.7), HOS-SS (40.1 ± 26.6 versus 73.4 ± 28.6), mHHS (58.3 ± 16.9 versus 77.1 ± 18.3) and VAS pain (75.9 ± 14.7 versus 19.1 ± 24.6) when comparing pre- and post-operative outcomes ($P < 0.001$) (Table II).

Association between PROs and CBT

Simple linear regression demonstrated an association between FCC and HOS-ADL (β: −0.248; $P = 0.01$), HOS-SS (β: −0.222; $P = 0.028$) and mHHS (β: −0.225; $P = 0.019$) (Table III). There was no linear association between FCI or Dorr classification type and any reported outcome score. Furthermore, VAS pain score did not have any statistically significant association between FCC, FCI or Dorr classification type.

Adding age and gender to the linear regression models demonstrated a continued linear relationship between FCC and HOS-ADL (β: −0.166; $P = 0.048$); however, there was no longer a statistically significant association with HOS-SS (β: −0.124; $P = 0.166$) and mHHS (β: −0.164; $P = 0.08$) (Table IV).

Table IV. Linear regression models including age and gender as effect modifiers

	Beta	*SE*	*P-value*
HOS-ADL			
FCC	−0.166	17.462	**0.048**
Age	−0.372	0.126	**<0.001**
Gender	−0.133	3.252	0.131
HOS-SS			
FCC	−0.124	26.393	0.166
Age	−0.482	0.196	**<0.001**
Gender	−0.047	4.982	0.593
mHHS			
FCC	−0.164	17.196	0.08
Age	−0.315	0.124	**0.001**
Gender	−0.037	3.203	0.683

Bold value indicate statistical significance (p-value<0.05).

Association between MCID and CBT indices

The logistic regression models demonstrated that FCC, FCI and Dorr Classification Type were not predictors MCID HOS-ADL, HOS-SS or mHHS (Table V). However, age was a predictor of achieving both MCID HOS-ADL and HOS-SS in all the regression models.

Clinical outcome analysis by age and gender categories

The study group was separated into age and gender categories to determine whether a certain age and gender group had lower reported outcome scores and lower CBT measures. There was a statistically significant difference in comparison of each group, with females ≥45 consistently

Table V. Logistic regression analysis of MCID and CBT indices

		95% CI		
	Exp(B)	*Lower*	*Upper*	*P-value*
MCID HOS-ADL				
FCC	0.953	0.007	130.382	0.985
Age	0.957	0.923	0.993	**0.02**
Gender	0.939	0.386	2.283	0.89
FCI	0.441	0	394.888	0.813
Age	0.956	0.921	0.993	**0.019**
Gender	0.921	0.376	2.256	0.856
Dorr type	1.252	0.582	2.694	0.565
Age	0.955	0.92	0.991	**0.016**
Gender	0.903	0.37	2.207	0.823
MCID HOS-SS				
FCC	0.149	0.001	29.424	0.48
Age	0.939	0.902	0.978	**0.002**
Gender	0.789	0.315	1.978	0.614
FCI	0.617	0.001	726.087	0.893
Age	0.937	0.899	0.976	**0.002**
Gender	0.767	0.304	1.938	0.575
Dorr type	1.278	0.582	2.805	0.541
Age	0.936	0.898	0.975	**0.002**
Gender	0.746	0.295	1.883	0.535
MCID mHHS				
FCC	0.606	0.005	78.262	0.84
Age	0.98	0.947	1.015	0.266
Gender	1.278	0.509	3.208	0.601
FCI	0.388	0	330.05	0.783
Age	0.979	0.945	1.014	0.242
Gender	1.23	0.482	3.138	0.665
Dorr type	1.527	0.685	3.402	0.3
Age	0.977	0.943	1.013	0.206
Gender	1.194	0.473	3.012	0.707

Bold value indicate statistical significance (p-value$<$0.05).

having the lowest HOS-ADL, HOS-SS and mHHS scores (Table VI). Furthermore, the same group had the highest pain score (29.9 ± 28.3; $P < 0.001$).

CBT indices analysis by age and gender categories

ANOVA analysis of FCC and FCI by age and gender category demonstrated a statistically significant difference among the 4 groups, with females $\geq$45 having the highest FCC average (0.64 ± 0.09; $P = 0.041$) and lowest FCI average (0.49 ± 0.07; $P = 0.011$) (Table VII). The chi-square test for trend showed a linear by linear association between Dorr classification type and gender/age group.

DISCUSSION

The primary finding of this study is that there is a linear association between FCC ratio and PRO scores. However, the effect of the association between HOS-SS and FCC is modified by age and gender. Furthermore, there was no association between the other CBT measures (femoral calcar index and Dorr classification type) and PRO scores. Analysis of gender and age group demonstrated that females $\geq$ 45 years of age appear to have both the lowest reported outcomes and CBT measures when compared with their male and younger counterparts. With the rising prevalence of deteriorating CBT in this demographic, the purpose of this study was to determine the associations between age, sex, CBT and post-operative outcomes following hip arthroscopy after FAIS. These results suggest that the inferior outcomes observed in females $\geq$ 45-years old may be attributable to reduced CBT.

The results of this study are congruent with literature reporting that age and sex are associated with clinical outcomes following hip arthroscopy. Bryan *et al.* [29] reported that although all patients improved significantly from baseline in terms of HOS scores, younger patients had superior outcomes at 2-years when compared with older patients. Importantly, degenerative change in the hip is a significant confounding factor among older patients that must be considered. A study by Philippon *et al.* [30] suggests that joint space is a significant predictor of conversion to total hip arthroplasty after hip arthroscopy in patients 50 years and older. This was confirmed in a study by Chandrasekaran *et al.* [31], who reported that hip arthroscopy has a limited role for patients with Tonnis Grade 2 osteoarthritis or higher.

Gender has also been demonstrated to influence the results of hip arthroscopy in patients with FAIS. Frank *et al.* [2] compared outcomes following hip arthroscopy for FAIS according to sex and age. In their study, female patients older than 45 years of age demonstrated the

Table VI. ANOVA for age and gender categories and PROs

	< 45 years of age		*≥ 45 years of age*		*P-value*
	Males	*Females*	*Males*	*Females*	
HOS-ADL	95.5 ± 6.3	95.4 ± 4.4	81.2 ± 16.2	69.3 ± 24.8	**<0.001**
HOS-SS	90.0 ± 12.9	90.8 ± 10.2	56.9 ± 31.3	46.9 ± 26.8	**<0.001**
mHHS	84.4 ± 9.5	86.3 ± 8.6	73.7 ± 16.3	67.4 ± 24.6	**<0.001**
VAS Pain	9.8 ± 16.1	6.8 ± 10.3	24.9 ± 24.9	29.9 ± 28.3	**<0.001**
VAS Satisfaction	91.5 ± 10.5	93.4 ± 9.8	91.1 ± 68.6	74.3 ± 31.8	0.228

Bold value indicate statistical significance (p-value<0.05).

Table VII. Analysis of CBT indices by age and gender category

CBT index	*< 45 years of age*		*≥ 45 years of age*		*P-value*
	Males	*Females*	*Males*	*Females*	
FCI	0.54 ± 0.07	0.52 ± 0.08	0.50 ± 0.06	0.49 ± 0.07	**0.011**
FCC	0.56 ± 0.1	0.57 ± 0.11	0.61 ± 0.07	0.64 ± 0.09	**0.041**
Dorr classification type					**0.018**
A	16 (32.7%)	13 (26.5%)	11 (22.4%)	9 (18.4%)	—
B	11 (20.3%)	13 (24.1%)	15 (27.8%	15 (27.8%)	—
C	0	1 (20%)	1 (20%)	3 (60%)	—

Bold value indicate statistical significance (p-value<0.05).

lowest post-operative outcome scores, while the females younger than 45 did as well as males in the same age group. The reason why females with FAIS over the age of 45 experience inferior outcomes when compared with their younger and male counterparts is unknown. From a musculoskeletal standpoint, an important risk factor in the older female population is declining BMD, which has been associated with the risk of fracture [32, 33]. In terms of post-operative outcomes after orthopedic sports medicine procedures, CBT (used a surrogate for BMD) has been extensively evaluated with regards to rotator cuff repair and has been implicated in anchor pullout and repair failure [34]. However, the effect of CBT on post-operative outcomes and failure in the realm of hip arthroscopy has not been well studied.

Although there is very limited literature evaluating preoperative BMD in patients undergoing hip arthroscopy for FAIS, one case report reported on changes in BMD following hip arthroscopy. Due to weight-bearing restrictions following surgery, a decrease in BMD is expected in the acute post-operative period. In the report, Mueller *et al.* [35] evaluated bone mass using DEXA scan and quantitative CT measurements of a female professional Ironman athlete before and after hip arthroscopy. As expected, the BMD of the proximal femur decreased post-operatively but returned to baseline after 4 months of rehabilitation. Therefore, patients with reduced CBT before undergoing hip arthroscopy, such as the ≥ 45 female cohort in this study, are likely at risk for further deterioration in CBT and potentially BMD following surgery. It is unclear to what degree their CBT may worsen, and what the clinical manifestations are, if any. Although further studies are certainly needed to more fully elucidate the interplay between age, sex, CBT and clinical outcomes, BMD and CBT are nevertheless a prevalent and potentially modifiable risk factors in certain patient populations that may warrant preoperative screening.

An important finding of this study was that while there was a linear association between CBT and outcomes, this association was not independent of gender and age. There is likely a multidimensional confluence of factors in the older female population that leads to inferior outcomes, involving not just CBT but also hormonal and metabolic changes, joint degeneration and activity level. Despite well-preserved joint space on plain radiographs with maintained cartilage thickness, there are likely degenerative changes on the cellular level that are difficult to appreciate grossly. With arthroscopic evaluation, signs of degradation in cartilage quality include yellowing, thin friable chondral surfaces and delamination. Whether this is related to age-related deterioration in CBT, perhaps through loss of subchondral bone strength and regenerative capacity, is not yet fully understood. Furthermore, we believe that it is important to acknowledge that although this study failed to identify an independent association between CBT and outcomes, the Dorr classification used only provides three categories of bone quality characterization. Future studies are warranted that utilize pre-operative DEXA scanning, as the use of a continuous statistic provided by DEXA values may allow for detection of more subtle associations between CBT and outcomes and may help limit potential confounding from age.

Limitations

This study is subject to several important limitations. The radiologic classifications as described by Dorr and used in subsequent studies is not a direct measure of BMD, but can be used as a surrogate for BMD as previously reported. Although it has been shown to have strong correlations with osteoporosis, the Dorr classification only provides insight on bone quality and density. Group sizes were relatively small, and may not be adequately powered to detect small differences in PROs and CBT between groups, particularly assessing differences in FCC and FCI. Additionally, plain radiographs were the only imaging modality used to assess CBT, and other techniques such as DEXA and CT scans may more fully capture a patient's overall metabolic bone status. Unfortunately, DEXA scans are usually not part of the standard of care in the patient population undergoing hip arthroscopy. CT scan, however, has increasingly become part of the standard pre-operative work-up, as it allows for improved characterization of the patient's bony anatomy in terms of FAIS and hip dysplasia. This may represent further research opportunities through using standard pre-operative CT scans to assess CBT with Hounsfield units.

CONCLUSION

Although hip arthroscopy is generally successful in patients with FAIS at relieving pain and restoring function, increasing age in combination with female sex has been associated with inferior post-operative outcomes. The results of this study also demonstrate that decreased FCC ratio is an independent predictor of worse post-operative outcomes following hip arthroscopy. Additional studies investigating the reason for worse outcomes in this population should consider other potential confounding variables with increasing age and female sex, such as joint degeneration, hormonal and metabolic changes and activity level.

ACKNOWLEDGEMENTS

Thank you to our clinical and research teams for the continued incredible support gathering data for this project and countless others to improve patient-care.

CONFLICT OF INTEREST STATEMENT

S.J.N. receives research support from Allosource, Arthrex, Inc., Athletico, DJ Orthopaedics, Linvatec, Miomed, Smith & Nephew and Stryker; education payments from Arthrex, Inc.; IP royalties from Ossur; consulting fees and hospitality payments from Stryker; and publishing royalties and financial/material support from Springer. He is a paid consultant for Ossur and Stryker; he is on the editorial/governing board of *American Journal of Orthopedics*; he is the board/committee member of American Orthopaedic Society for Sports Medicine and Arthroscopy Association of North America. B.G. receives research support from Arthrex; and travel and lodging fees from Prodigy Surgical Distribution, Inc. and Exactech, Inc. He is a paid consultant for Arthrex, Smith & Nephew, Inc. and Carticept Medical, Inc.; he is a paid presenter/speaker for Arthrex and Smith & Nephew, Inc.

REFERENCES

1. Frank RM, Lee S, Bush-Joseph CA *et al*. Improved outcomes after hip arthroscopic surgery in patients undergoing T-capsulotomy with complete repair versus partial repair for femoroacetabular impingement: a comparative matched-pair analysis. *Am J Sports Med* 2014; **42**: 2634–42.
2. Frank RM, Lee S, Bush-Joseph CA *et al*. Outcomes for hip arthroscopy according to sex and age: a comparative matched-group analysis. *J Bone Joint Surg Am* 2016; **98**: 797–804.
3. Damborg F, Nissen N, Jørgensen HRI *et al*. Changes in bone mineral density (BMD) around the cemented Exeter stem: a prospective study in 18 women with 5 years follow-up. *Acta Orthopaedica* 2008; **79**: 494–8.
4. Cawthon PM. Gender differences in osteoporosis and fractures. *Clin Orthop Relat Res* 2011; **469**: 1900–5.
5. Nguyen ND, Ahlborg HG, Center JR *et al*. Residual lifetime risk of fractures in women and men. *J Bone Miner Res* 2007; **22**: 781–8.

6. Sah AP, Thornhill TS, LeBoff MS, Glowacki J. Correlation of plain radiographic indices of the hip with quantitative bone mineral density. *Osteoporos Int* 2007; **18**: 1119–26.
7. Bonnick SL. HSA: beyond BMD with DXA. *Bone* 2007; **41**: S9–12.
8. Garg MK, Kharb S. Dual energy X-ray absorptiometry: pitfalls in measurement and interpretation of bone mineral density. *Indian J Endocrinol Metab* 2013; **17**: 203–10.
9. Szulc P, Duboeuf F, Schott AM *et al*. Structural determinants of hip fracture in elderly women: re-analysis of the data from the EPIDOS study. *Osteoporos Int* 2006; **17**: 231–6.
10. Patterson J, Rungprai C, Den Hartog T *et al*. Cortical bone thickness of the distal part of the tibia predicts bone mineral density. *J Bone Joint Surg Am* 2016; **98**: 751–60.
11. He QF, Sun H, Shu LY *et al*. Radiographic predictors for bone mineral loss: cortical thickness and index of the distal femur. *Bone Joint Res* 2018; **7**: 468–75.
12. Nguyen BN, Hoshino H, Togawa D, Matsuyama Y. Cortical thickness index of the proximal femur: a radiographic parameter for preliminary assessment of bone mineral density and osteoporosis status in the age 50 years and over population. *Clin Orthop Surg* 2018; **10**: 149–56.
13. Russell LA. Osteoporosis and orthopedic surgery: effect of bone health on total joint arthroplasty outcome. *Curr Rheumatol Rep* 2013; **15**: 371.
14. Deyo RA, Mirza SK. Trends and variations in the use of spine surgery. *Clin Orthop Relat Res* 2006; **443**: 139–46.
15. Frankel BM, Jones T, Wang C. Segmental polymethylmethacrylate-augmented pedicle screw fixation in patients with bone softening caused by osteoporosis and metastatic tumor involvement: a clinical evaluation. *Neurosurgery* 2007; **61**: 531–7; discussion 37–8.
16. Slikker W 3rd, Van Thiel GS, Chahal J, Nho SJ. The use of double-loaded suture anchors for labral repair and capsular repair during hip arthroscopy. *Arthrosc Tech* 2012; **1**:e213–7.
17. Harris JD, Slikker W 3rd, Gupta AK *et al*. Routine complete capsular closure during hip arthroscopy. *Arthrosc Tech* 2013; **2**: e89–94.
18. Leong NL, Clapp IM, Neal WH *et al*. The influence of pain in other major joints and the spine on 2-year outcomes after hip arthroscopy. *Arthroscopy* 2018; **34**: 3196–201.
19. Malloy P, Gray K, Wolff AB. Rehabilitation after hip arthroscopy: a movement control-based perspective. *Clin Sports Med* 2016; **35**: 503–21.
20. Martin RL, Kelly BT, Philippon MJ. Evidence of validity for the hip outcome score. *Arthroscopy* 2006; **22**: 1304–11.
21. Martin RL, Philippon MJ. Evidence of reliability and responsiveness for the hip outcome score. *Arthroscopy* 2008; **24**: 676–82.
22. Byrd JW. Hip arthroscopy: patient assessment and indications. *Instr Course Lect* 2003; **52**: 711–9.
23. Harris WH. Traumatic arthritis of the hip after dislocation and acetabular fractures: treatment by mold arthroplasty. An end-result study using a new method of result evaluation. *J Bone Joint Surg Am* 1969; **51**: 737–55.
24. Nwachukwu BU, Fields K, Chang B *et al*. Preoperative outcome scores are predictive of achieving the minimal clinically important difference after arthroscopic treatment of femoroacetabular impingement. *Am J Sports Med* 2017; **45**: 612–9.
25. Levy DM, Cvetanovich GL, Kuhns BD *et al*. Hip arthroscopy for atypical posterior hip pain: a comparative matched-pair analysis. *Am J Sports Med* 2017; **45**: 1627–32.
26. Katz NP, Paillard FC, Ekman E. Determining the clinical importance of treatment benefits for interventions for painful orthopedic conditions. *J Orthop Surg Res* 2015; **10**: 24.
27. Clohisy JC, Carlisle JC, Beaule PE *et al*. A systematic approach to the plain radiographic evaluation of the young adult hip. *J Bone Joint Surg Am* 2008; **90(Suppl 4)**: 47–66.
28. Dorr LD, Faugere MC, Mackel AM *et al*. Structural and cellular assessment of bone quality of proximal femur. *Bone* 1993; **14**: 231–42.
29. Bryan AJ, Krych AJ, Pareek A *et al*. Are short-term outcomes of hip arthroscopy in patients 55 years and older inferior to those in younger patients? *Am J Sports Med* 2016; **44**: 2526–30.
30. Philippon MJ, Briggs KK, Carlisle JC, Patterson DC. Joint space predicts THA after hip arthroscopy in patients 50 years and older. *Clin Orthop Relat Res* 2013; **471**: 2492–6.
31. Chandrasekaran S, Darwish N, Gui C *et al*. Outcomes of hip arthroscopy in patients with tonnis grade-2 osteoarthritis at a mean 2-year follow-up: evaluation using a matched-pair analysis with tonnis grade-0 and grade-1 cohorts. *J Bone Joint Surg Am* 2016; **98**: 973–82.
32. Cummings SR, Nevitt MC, Browner WS *et al*. Risk factors for hip fracture in white women. Study of Osteoporotic Fractures Research Group. *N Engl J Med* 1995; **332**: 767–73.
33. Unnanuntana A, Gladnick BP, Donnelly E, Lane JM. The assessment of fracture risk. *J Bone Joint Surg Am* 2010; **92**: 743–53.
34. Chung SW, Oh JH, Gong HS *et al*. Factors affecting rotator cuff healing after arthroscopic repair: osteoporosis as one of the independent risk factors. *Am J Sports Med* 2011; **39**: 2099–107.
35. Mueller SM, Braendli S, Toigo M. Alterations in bone mineral density and lower extremity lean mass after hip arthroscopy in a professional female Ironman triathlete: a case study. *Springerplus* 2015; **4**: 70.