Application of Machine Learning for Predicting Clinically Meaningful Outcome After Arthroscopic Femoroacetabular Impingement Surgery

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Background: Hip arthroscopy has become an important tool for surgical treatment of intra-articular hip pathology. Predictive models for clinically meaningful outcomes in patients undergoing hip arthroscopy for femoroacetabular impingement syndrome (FAIS) are unknown.

Purpose: To apply a machine learning model to determine preoperative variables predictive for achieving the minimal clinically important difference (MCID) at 2 years after hip arthroscopy for FAIS.

Study Design: Case-control study; Level of evidence, 3.

Methods: Data were analyzed for patients who underwent hip arthroscopy for FAIS by a high-volume fellowship-trained surgeon between January 2012 and July 2016. The MCID cutoffs for the Hip Outcome Score–Activities of Daily Living (HOS-ADL), HOS–Sport Specific (HOS-SS), and modified Harris Hip Score (mHHS) were 9.8, 14.4, and 9.14, respectively. Predictive models for achieving the MCID with respect to each were built with the LASSO algorithm (least absolute shrinkage and selection operator) for feature selection, followed by logistic regression on the selected features. Study data were analyzed with PatientIQ, a cloud-based research and analytics platform for health care.

Results: Of 1103 patients who met inclusion criteria, 898 (81.4%) had a minimum of 2-year reported outcomes and were entered into the modeling algorithm. A total of 74.0%, 73.5%, and 79.9% met the HOS-ADL, HOS-SS, and mHHS threshold scores for achieving the MCID. Predictors of not achieving the HOS-ADL MCID included anxiety/depression, symptom duration for >2 years before surgery, higher body mass index, high preoperative HOS-ADL score, and preoperative hip injection (all $P < .05$). Predictors of not achieving the HOS-SS MCID included anxiety/depression, preoperative symptom duration for >2 years, high preoperative HOS-SS score, and preoperative hip injection, while running at least at the recreational level was a predictor of achieving HOS-SS MCID (all $P < .05$). Predictors of not achieving the mHHS MCID included history of anxiety or depression, high preoperative mHHS score, and hip injections, while being female was predictive of achieving the MCID (all $P < .05$).

Conclusion: This study identified predictive variables for achieving clinically meaningful outcome after hip arthroscopy for FAIS. Patient factors including anxiety/depression, symptom duration >2 years, preoperative intra-articular injection, and high preoperative outcome scores are most consistently predictive of inability to achieve clinically meaningful outcome. These findings have important implications for shared decision-making algorithms and management of preoperative expectations after hip arthroscopy for FAI.

Keywords: femoroacetabular impingement syndrome; PatientIQ; MCID; Hip Outcome Score; modified Hip Harris Score; predictive modeling

The arthroscopic treatment of femoroacetabular impingement (FAI) syndrome (FAIS) has been shown to reliably alleviate symptomatic hip pain and disability.[4,29,37,42,46,48] Over the past decade, advancements in surgical instrumentation, techniques, and our understanding of intra-articular hip pathology have resulted in a dramatic increase in the number of elective hip arthroscopic procedures performed to treat FAIS.[36,44] Furthermore, an abundance of studies has demonstrated statistically significant improvements in certain patient-reported outcomes (PROs), such as the

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modified Harris Hip Score (mHHS), Hip Outcome Score–Activities of Daily Living (HOS-ADL), and HOS–Sport Specific (HOS-SS) after hip arthroscopy for FAIS.[37,50,56]

Previous studies have demonstrated that statistical significance of PRO improvement is not necessarily equivalent to clinical meaningfulness; thus, the minimal clinically important difference (MCID) has been employed to measure the smallest difference between pre- and postoperative PRO measurements in patients that signifies a change in symptoms.[23,51] Over the past decade, the MCID has gained popularity as a reporting metric for interpreting clinical significance.[11,16,33,42] The primary advantage of measuring the MCID as compared with statistically significant improvement in PROs is that it represents a tangible clinical treatment target.[2]

While prior studies have identified increased patient age, increased Tönnis grade, and decreased joint space width as risk factors for revision surgery or conversion arthroplasty, more recent hip arthroscopy literature has sought to better understand the MCID and predictors for achieving this clinical outcome in hopes to better define surgical outcomes and develop decision-making algorithms.[9,13,26,42] For the treatment of FAIS arthroscopically, the MCIDs for the most commonly used PROs, such as the HOS-ADL, mHHS, and HOS-SS, have been defined.[8,25,32] Despite increased utilization and widespread acceptance of arthroscopic techniques to treat FAIS, few studies have sought to identify risk factors associated with failure to achieve clinically meaningful outcomes after hip arthroscopy for FAIS based on MCID criteria.[12,13,19,35,43]

Therefore, the purpose of the present study was to apply a machine learning model to determine which preoperative variables can predict whether a patient will achieve MCID at postoperative 2 years from hip arthroscopy for FAIS.

METHODS

Patient Characteristics

This study was approved by the institutional review board of the senior author's (S.J.N.) institution. Prospective data on all patients undergoing hip arthroscopy for the treatment of FAIS by a single fellowship-trained surgeon (S.J.N.) were collected and analyzed in a clinical repository. All patients undergoing primary hip arthroscopy for the treatment of FAIS between January 1, 2012, and July 1, 2016, were included in this study. Inclusion criteria consisted of clinical and radiographic diagnosis of symptomatic FAIS,[18] failure of nonoperative management (physical therapy, activity modification, oral nonsteroidal anti-inflammatory drugs, and for some patients fluoroscopically guided intra-articular cortisone injection), and hip arthroscopy to address the FAIS with a minimum 2-year follow-up. Of note, hip injections were for equivocal diagnoses of FAI and were more routinely used for diagnostic purposes. Exclusion criteria consisted of hip arthroscopy for an indication other than FAIS, previous ipsilateral hip surgery, signs of osteoarthritis (Tönnis grade >1), hip dysplasia (lateral center-edge angle <20°), and a history of congenital hip disorders (slipped capital femoral epiphysis, developmental hip dysplasia, etc). Patient demographics and clinical factors, such as history of anxiety/depression, were abstracted from the available medical records.

Radiographic Analysis

All patients had a series of preoperative radiographs and a series of final follow-up radiographs.[59] Each series consisted of a standing anteroposterior pelvis radiograph, an anteroposterior hip radiograph, a false-profile hip radiograph, and a Dunn 45° lateral hip radiograph.[10] The alpha angle was measured, and the Tönnis grade was assessed on the anteroposterior, false-profile, and Dunn 45° lateral hip views.[27,38,54] The joint space width was measured in 3 positions on the anteroposterior hip radiograph, as were the acetabular inclination (Tönnis angle) and lateral center-edge angle of Wiberg.[10,27]

Functional Outcome Evaluation

Preoperatively, patient data were collected, including sex, age, operative extremity, body mass index (BMI), sports participation, duration of symptoms, and comorbidities. All patients completed preoperative and minimum 2-year postoperative hip-specific PRO instruments, including the HOS-ADL,[32] HOS-SS, and mHHS.[3,21] In addition, all patients graded their pre- and postoperative pain levels and postoperative satisfaction levels using a paper-based visual analog scale (VAS; 0-100 mm).

To quantify the clinical meaningfulness of outcome achievement of the HOS-ADL, HOS-SS, and mHHS, we

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applied the principles of the MCID as defined for functional PRO measures.[42] Previous work has proposed that the MCID be considered a minimum target for outcome improvement.[39] The MCID for 2-year HOS-ADL, HOS-SS, and mHHS was determined by calculating the half standard deviation of each hip-specific functional score (ie, HOS-ADL, HOS-SS, and mHHS) in the study patients, as described in the literature.[24,30,40,42] Among included patients at preoperative assessment, 788, 754, and 752 had complete assessments on the HOS-ADL, HOS-SS, and mHHS, respectively. At the postoperative assessment, 898, 822, and 823 had complete assessments.

Surgical Technique

All hip arthroscopies were performed by a single fellowship-trained hip surgeon at a high-volume academic hospital using a technique that has been well-described in the literature.[17,20,49] Briefly, standard anterolateral and midanterior portals were established under traction with the aid of fluoroscopic guidance. A 2-cm interportal capsulotomy was created, and pathology was addressed in the central compartment. Depending on intra-articular findings, central compartment procedures included acetabuloplasty, labral repair, and labral debridement. Next, after traction release, the interportal capsulotomy was extended inferiorly at the midpoint to create a T-capsulotomy for access to the peripheral compartment. The medial and lateral leaflets of the iliofemoral ligament were retracted with sutures for increased visualization. Cam deformity was meticulously resected until an adequate femoral head-neck offset was achieved. Upon completion, a dynamic examination of the operative leg was performed to confirm an appropriate resolution of impingement. The capsule was then repaired with a suture shuttling system, and plication was performed depending on degree of capsular laxity.

Postoperative Rehabilitation

Rehabilitation started on postoperative day 1 for all patients as previously described and did not differ from therapy indicated for primary FAIS cases.[28,31] Patients went through a 4-phase rehabilitation protocol that lasted an average of 16 to 18 weeks (Appendix Table A1, available in the online version of this article). Rehabilitation phase 1 prioritized joint protection and soft tissue mobilization techniques. The surgical limb was initially restricted to 20-pound foot-flat weightbearing during this phase. Patients advanced to phase 2 if they demonstrated full weightbearing capabilities. Phase 2 concentrated on normal gait maintenance, full range of motion restoration, 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 preinjury 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.

Statistical Analysis

Data was screened to ensure it met parametric statistical assumptions prior to analysis. Descriptive statistics for all continuous variables are reported as means and standard deviations, and frequency statistics were reported for all non-continuous variables unless otherwise stated. Paired samples *t* tests were used to compare preoperative and two-year postoperative patient reported outcome scores in FAIS patients. Predictive models for achieving the MCID with respect to the HOS-ADL, HOS-SS, and mHHS were each built in the following 2-step process: (1) feature selection with least absolute shrinkage and selection operator (LASSO) and (2) binary logistic regression with a generalized linear model.

Feature Selection With LASSO. To reduce the data set to its most meaningful features, the LASSO algorithm was utilized. The LASSO technique was originally a technique for improving ordinary least squares estimates; this technique has been extended to generalized linear models and survival models as well.[52] LASSO shrinks the coefficients of some features, a concept known as "shrinkage," to reduce variance, and it sets the others to zero, where those features with a coefficient of zero are interpreted as not being selected.[53]

As compared with commonly used feature selection methods, such as stepwise selection and principal component analysis, LASSO has a strong combination of advantages (for comparative advantages of various selection methods, see Appendix Table A2, available online). While principal component analysis is typically used as a dimensionality reduction technique to retain the top few components for modeling, authors disagree over how to rigorously interpret these components in terms of the original features.[5] Often, the interpretations suggest that the features included in the top components exhibit the strongest effects and shall be retained for modeling. However, analyses have demonstrated that those features are not necessarily the best subset of its size.[5]

Conversely, the LASSO technique is interpretable just like any linear model, by virtue of expressing feature selection with nonzero estimated coefficient. It is stable—small changes in data do not result in appreciably different models.[52] Finally, it is computationally efficient, as the underlying problem is a constrained optimization, which can be solved with quadratic programming. Although stepwise feature selection, particularly forward selection, is a relatively straightforward procedure, this approach has been criticized as having a solution that tends to be locally optimal, owing to its elimination of useful predictors that happen to be correlated with predictors that it had already selected in previous steps.[14,52] The LASSO technique, however, updates the coefficient estimates to maintain equal absolute correlation of all active variables with the residual.[22]

Modeling Process. For each PRO measure (HOS-ADL, HOS-SS, and mHHS), the data set of patients meeting inclusion and exclusion criteria and not exhibiting missingness for any of the variables listed in the "data dictionary" (Appendix Table A3, available online) is entered into the 2-step modeling process. As such, a patient with pre- and postoperative

TABLE 1
Patient Characteristics

	Mean ± SD or n (%)
Age, y	32.9 ± 12.2
Sex	
Male	386 (35.0)
Female	717 (65.0)
Body mass index	25.1 ± 5.0
History of anxiety/depression	147 (13.3)
History of back pain	148 (13.4)
Preoperative symptom duration >2 y	313 (28.4)
Preoperative hip injection	528 (58.8)
Sports participation	775 (70.3)
Running	594 (53.9)

outcome data, as well as data available for every variable in the data dictionary, was considered to have a "complete observation." The variables listed in the data dictionary were selected from the original surgical repository for their data quality—low "missingness" and high confidence in their accuracy. Some are selected out of demonstration in prior research of their predictive power (eg, sex, age, BMI).

A LASSO model was fitted on the data set, regressing on the dependent variable (achieving the MCID with respect to the PRO measure). A set of features (variables) with nonzero coefficients is produced; these features are then utilized to perform a binary logistic regression analysis.

To determine whether the predictive models had a good fit with the study group, receiver operating characteristic curve analysis and log-likelihood chi-square tests were used. For receiver operating characteristic curve analysis, an area under the curve >0.800 was considered to be an excellent fit. Log-likelihood chi-square tests were used to assess goodness of fit, where low *P* values indicated that the model was properly specified. Cross-validation was also employed to verify the consistency of the modeling process and its results.

Study data were analyzed with PatientIQ (PatientIQ), a cloud-based research and analytics platform for health care. The PatientIQ platform was designed to integrate disparate data sources, such as data residing in the electronic health record, and provide a real-time data exploration interface and advanced statistics engine. In addition, the platform offers capabilities to capture data directly from patients, clinical staff, and researchers at various pre- and postoperative time points via workflows specific to a given diagnosis and/or procedure. In the current study, the senior author's data repository was imported into PatientIQ for the purpose of utilizing the statistical software. PROs were captured electronically and during clinical encounters before import into PatientIQ.

RESULTS

After application of inclusion and exclusion criteria, 1103 patients were identified, of which 898 (81.4%) had a minimum of 2-year reported outcomes and were entered into the modeling algorithm. The patient characteristics are summarized in Table 1. The study population had a mean ± SD age and BMI of 32.9 ± 12.2 years and 25.1 ± 5.0 kg/m^2, respectively. Most of the patients participated in sports (70.3%), while 53.9% self-reported being runners. A total of 313 patients (28.4%) reported having symptoms lasting >2 years before surgery. The majority of patients had undergone labral repair (n = 884; 80.1%).

TABLE 2
Analysis of Radiographic Parameters[a]

	Preoperative	Postoperative	*P* Value
Alpha angle			
Anteroposterior	76.4 ± 12.0	44.1 ± 5.3	<.001
Dunn 45°	65.4 ± 11.5	38.2 ± 4.3	<.001
False profile	64.8 ± 12.3	41.0 ± 4.9	<.001
Center-edge angle			
Lateral	31.1 ± 6.0	28.4 ± 5.5	<.001
Anterior	33.4 ± 6.8	30.6 ± 6.3	<.001
Tönnis grade, n (%)			
0	743 (94.2)		
1	52 (5.8)		
Tönnis angle	6.4 ± 4.6	6.0 ± 4.2	.521

[a]Data are provided as mean ± SD unless otherwise noted.

Radiographic Parameters

Analysis of pre- and postoperative radiographic findings is summarized in Table 2. There was a statistically significant difference between pre- and postoperative alpha angles (anteroposterior, false-profile, and Dunn 45° views), as well as lateral and anterior center-edge angles. There was no statistically significant difference between pre- and postoperative Tönnis angles. The majority of patients did not have any arthritic changes seen on plain radiographs (Tönnis grade 0 = 94.2%).

Analysis of Pre- and Postoperative PROs

Paired *t* test analysis of pre- and postoperative (2-year minimum) PROs is reported in Table 3. There was a statistically significant increase in HOS-ADL (65.0 ± 18.8 vs 86.7 ± 16.1; $P < .001$), HOS-SS (42.9 ± 22.7 vs 75.1 ± 24.7; $P < .001$), and mHHS (57.3 ± 14.8 vs 80.6 ± 16.8; $P < .001$) at 2 years postoperatively. Furthermore, there was a significant reduction in reported VAS pain (67.8 ± 20.2 vs 20.9 ± 23.9; $P < .001$).

Analysis of MCID Thresholds and Preoperative Predictors of Achieving MCID

The HOS-ADL, HOS-SS, and mHHS threshold scores for achieving MCID were 9.8, 14.4, and 9.14, respectively. Of patients entered into the 2-step modeling procedure described in the Statistical Analysis section, 74.0% met the HOS-ADL threshold score for achieving the MCID; 73.5%, the HOS-SS; and 79.9%, the mHHS (Table 4). The significant preoperative predictors for achieving the threshold HOS-ADL, HOS-SS, and mHHS scores for the MCID are summarized in Table 5. While the set of significant predictors

TABLE 3
Comparison of Pre- and Postoperative Patient-Reported Outcomes[a]

	Preoperative	Postoperative	*P* Value
HOS-ADL	65.0 ± 18.8	86.7 ± 16.1	<.001
HOS-SS	42.9 ± 22.7	75.1 ± 24.7	<.001
mHHS	57.3 ± 14.8	80.6 ± 16.8	<.001
VAS			
Pain	67.8 ± 20.2	20.9 ± 23.9	<.001
Satisfaction		80.8 ± 29.1	

[a]Data are provided as mean ± SD. HOS-ADL, Hip Outcome Score–Activities of Daily Living; HOS-SS, Hip Outcome Score–Sport Specific; mHHS, modified Harris Hip Score; VAS, visual analog scale.

TABLE 4
Frequencies of Patients Achieving Threshold Scores for MCID[a]

	MCID, n (%)	
	Achieved	Not Achieved
HOS-ADL	503 (74.0)	177 (26.1)
HOS-SS	458 (73.5)	165 (26.5)
mHHS	496 (79.9)	125 (20.1)

[a]HOS-ADL, Hip Outcome Score–Activities of Daily Living; HOS-SS, Hip Outcome Score–Sport Specific; MCID, minimal clinically important difference; mHHS, modified Harris Hip Score.

differed for each hip-specific outcome measure, there were some commonalities. The use of preoperative injections and a past or present anxiety/depression condition each had a statistically significant negative association with achieving the threshold MCID for all 3 measures. Preoperative symptom duration >2 years also had a statistically significantly negative association with achieving the threshold MCID for the HOS-ADL and HOS-SS. Also, despite the inclusion of features describing results of pain provocation and mobility tests, such as a positive trochanteric pain sign and proximal hamstring, very few of those features were determined to be predictive.

The predictive models for the HOS-ADL, HOS-SS, and mHHS MCID demonstrated excellent fit with the study group (all area under the curve >0.800) (Figure 1).

For the HOS-ADL MCID, 388 complete observations with respect to the variables listed in the data dictionary (Appendix Table A3, available online) were entered into the 2-step modeling process. LASSO regression identified 27 highly predictive variables listed in Appendix Table A4 ("LASSO Coef" column; available online). The variables of significance ($P < .05$) in the logistic regression model for the HOS-ADL MCID are listed in Table 5 ("Predictors of Achieving HOS-ADL MCID"). The full model is described in Appendix Table A4.

A log-likelihood chi-square test was used to evaluate the goodness of fit of the logistic regression model; the model as a whole was statistically significant ($\chi^2 = 164.90$; $df = 27$; $P < .001$). Not only was the final model itself validated, but so was the methodology, on the basis of 10-fold cross-validation. Ten-fold cross-validation results for the HOS-ADL, HOS-SS, and mHHS are presented in Appendix Table A7 and Appendix Figures A1-A3 (available online).

TABLE 5
Significant LASSO and Logistic Regression Analysis of Preoperative Predictors for Achieving HOS-ADL, HOS-SS, and mHHS Threshold Scores for the MCID[a]

	Odds Ratio	95% CI
Predictors of achieving HOS-ADL MCID		
History of anxiety or depression	0.396	0.164-0.956
Trochanteric pain sign: positive	5.368	1.525-18.90
Preoperative symptoms >2 y	0.457	0.247-0.847
Age 30-45 y	0.445	0.221-0.893
Increasing body mass index	0.878	0.805-0.959
Preoperative		
HOS-ADL score	0.905	0.870-0.941
mHHS score	1.043	1.008-1.0779
Hip injection	0.270	0.141-0.517
Predictors of achieving HOS-SS MCID		
Running	2.04	1.090-3.808
Anxiety/depression	0.374	0.173-0.811
Proximal hamstring	0.073	0.007-0.808
Preoperative		
Symptoms: >2 y	0.538	0.298-0.972
HOS-SS score	0.931	0.909-0.952
Hip injection	0.270	0.147-0.498
Predictors of achieving mHHS MCID		
Sex (female)	2.505	1.224-5.129
History of anxiety or depression	0.405	0.168-0.976
Proximal hamstring	0.070	0.005-0.951
Snapping iliotibial band	0.122	0.032-0.471
Preoperative		
Symptoms: 1-2 y	2.928	1.324-6.475
Symptoms: 6-12 mo	2.434	1.076-5.507
mHHS score	0.943	0.909-0.977
Hip injection	0.398	0.215-0.736

[a]HOS-ADL, Hip Outcome Score–Activities of Daily Living; HOS-SS, Hip Outcome Score–Sport Specific; LASSO, least absolute shrinkage and selection operator; MCID, minimal clinically important difference; mHHS, modified Harris Hip Score.

For the HOS-SS MCID, 370 complete observations with respect to the variables in the data dictionary were used for modeling. LASSO regression identified 18 highly predictive variables, listed in Appendix Table A5 ("LASSO Coef" column; available online). These variables were used to fit a logistic regression model for the HOS-SS MCID. Variables of significance ($P < .05$) are listed in Table 5 (section "Predictors of Achieving HOS-SS MCID"). The full model is described in Appendix Table A5. A log-likelihood chi-square test was used to evaluate the goodness of fit of the logistic regression model; the model as a whole was statistically significant ($\chi^2 = 115.285$; $df = 18$; $P < .001$).

For the mHHS MCID, 368 complete observations were entered into the modeling process. LASSO regression identified 23 highly predictive variables, listed in Appendix Table A6 ("LASSO Coef" column; available online). These

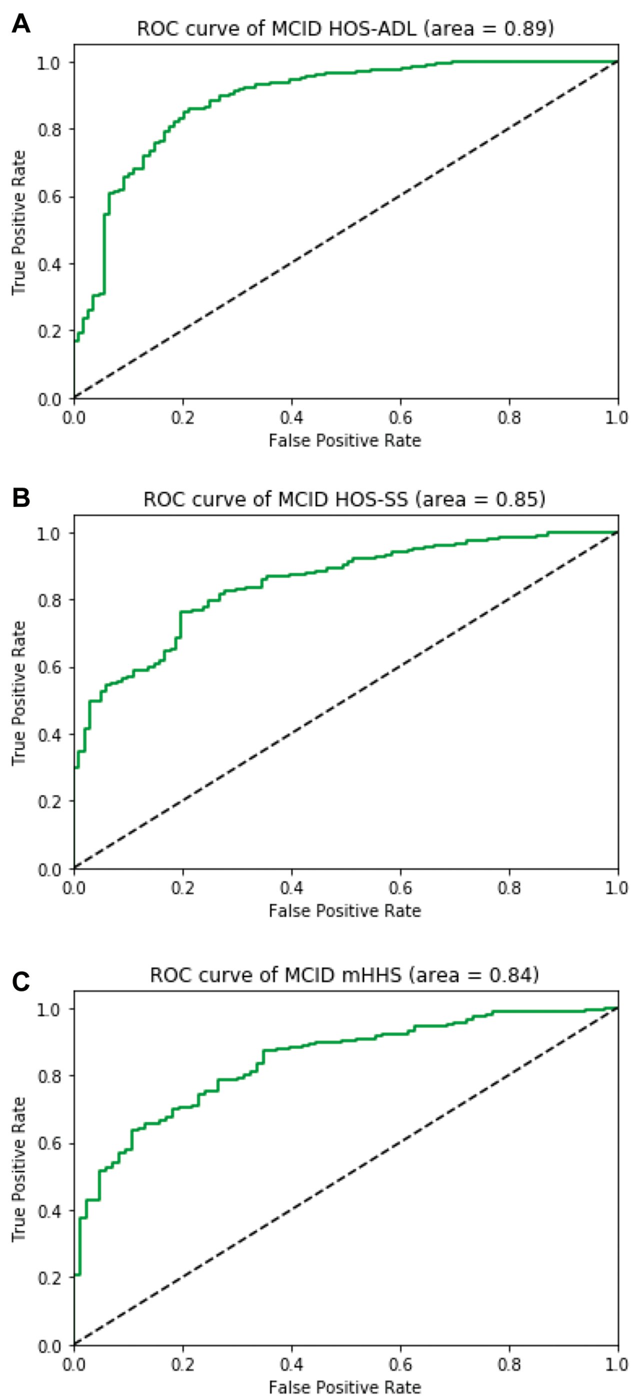

Figure 1. Receiver operating characteristic (ROC) curve analysis for determining the appropriate fit of the MCID predictive model: (A) HOS-ADL, (B) HOS-SS, and (C) mHHS. HOS-ADL, Hip Outcome Score–Activities of Daily Living; HOS-SS, Hip Outcome Score–Sport Specific; MCID, minimal clinically important difference; mHHS, modified Harris Hip Score.

variables were used to fit a logistic regression model for the mHHS MCID. Variables of significance ($P < .05$) are listed in Table 5 ("Predictors of Achieving mHHS MCID"). The full model is described in Appendix Table A6. A log-likelihood chi-square test was used to evaluate the goodness of fit of the logistic regression model; the model as a whole was statistically significant ($\chi^2 = 97.775$; $df = 23$; $P < .001$).

DISCUSSION

This study presents a detailed predictive model for achieving the MCID with respect to the HOS-ADL, HOS-SS, and mHHS entirely on the basis of preoperative data after recent hip arthroscopic surgery for FAIS. Several preoperative patient factors, including anxiety/depression, preoperative symptom duration >2 years, and preoperative intra-articular injections, predicted failure to achieve the MCID at 2 years for several PRO measures.

With advancements in the understanding and treatment of nonarthritic hip pain, the paradigm of defining clinical success within the hip preservation field has shifted from radiographic measurements and survivorship metrics to validated, patient-centered, clinically meaningful differences. The MCID has gained importance as a clinically meaningful outcome of measurable improvement.[2] An increasing number of studies has favored its use beyond reporting other statistically significant findings, as the MCID represents a more tangible and clinically relevant result.[13,16,40,58] The PROs examined in the current study are hip-specific validated outcome measures for the arthroscopic treatment of FAI, with the exception of the mHHS.[34] In the current study 74% of patients met the MCID for the HOS-ADL, >73% for the HOS-SS, and >79% for the mHHS. The consistency of MCID achievement across studies is important to the universal acceptance of this metric for measuring the success after hip arthroscopy for FAI. Using MCID thresholds, the current study examined the largest cohort to date of patients undergoing hip arthroscopy for FAI and showed similar values to those reported in the existing literature.[39,41,42]

Patients who had higher preoperative PROs and who underwent at least 1 preoperative injection were less likely to achieve the MCID for all PROs tested. These findings validate those of authors in the broader literature who also investigated how preoperative PROs predict achievement of the MCID. Nwachukwu et al[42] reviewed 364 patients from a prospective institutional hip preservation registry to identify predictors for achieving the MCID for the mHHS, HOS, and international Hip Outcome Tool (iHOT-33) at 1 year postoperatively. The group reported that the highest predictive value for whether patients will achieve the MCID at 1 year was preoperative PROs above the described threshold levels. Similarly, Cvetanovich et al[13] reviewed 384 patients with a minimum 2-year follow-up and reported that lower PROs were associated with achieving the MCID outcome measures. The current study adds to the existing literature by studying a cohort nearly 3 times that in the current literature and examining preoperative PROs as a continuous variable rather than as a binary threshold value. A higher preoperative PRO score was negatively associated with achieving each specific MCID. More granular, predictive data will help inform surgeons and patients on their ability to have clinically meaningful improvement after surgery.

The only other preoperative variable negatively associated with achieving all MCIDs studied was receiving a preoperative hip injection. While preoperative injections are considered an appropriate diagnostic and therapeutic modality in patients with FAI-related hip pain, limited research has examined how preoperative injections affect clinical outcomes at 2 years. We found that number of preoperative injections was negatively associated with achieving the MCID for the HOS-ADL, HOS-SS, and mHHS at 2 years. In the broader literature, preoperative injections have been associated with postoperative infection after hip arthroscopy, revision surgery after arthroscopic rotator cuff repair, and inferior outcomes after carpal tunnel release.[6,7,55,57,60] The theories for inferior outcomes after arthroscopic FAIS correction in a patient who has received preoperative corticosteroid injections are numerous; however, many center on the idea that corticosteroids may lead to tissue compromise and deterioration at the labral-bone healing interface after surgery. While the exact mechanism is beyond the scope of the current study, the association between receiving preoperative injections and failure to achieve the MCID for multiple PROs is of high clinical importance. However, it is worth noting that there may be an inherent selection bias in who receives hip injections. Patients receiving injections in our study included those with diagnostic intra-articular injections, as well as those receiving intra-articular injection as a primary form of therapy. However, most hip injections were for equivocal diagnoses of FAI and were more routinely used for diagnostic purposes. While not explicitly stated in charts during data gathering, it is possible that some patients received preoperative hip injections because they were more interested in avoiding surgery and possibly skeptical that surgery will help. Future studies may consider assessing whether there are differences in outcome based on hip joint injection for diagnostic versus therapeutic purposes.

Significant negative predictors of achieving the MCID for the HOS-ADL and HOS-SS included anxiety or depression in addition to symptom duration >2 years. Few studies have examined the association between psychiatric disorders in the patient population with FAI and surgical outcomes.[15,45] Ernat et al[15] studied 93 active duty patients undergoing hip arthroscopy for FAI and reported significantly poorer mHHS scores, Western Ontario and McMaster Universities Osteoarthritis Index scores, and Veterans RAND 12-Item Health Survey mental scores at 3-year follow-up in patients with anxiety disorders and major depression, among other psychiatric diagnoses. The current study adds to this developing literature by showing a negative association between history of anxiety or depression and ability to achieve the MCID for the HOS-SS and HOS-ADL at 2 years.

Similarly, patients with symptomatic impingement >2 years before surgery were less likely to achieve the MCID for these PROs. Basques et al[1] examined 624 patients, 235 (37.7%) of whom reported preoperative symptoms of $\geq$2 years. When compared with patients with a shorter duration of preoperative symptoms, these patients had significantly worse PROs and were significantly less likely to achieve a patient-acceptable symptomatic state for the HOS-ADL and HOS-SS at 2 years. The current study corroborated these data and reported that patients with prolonged preoperative symptoms are also less likely to achieve the MCID for the HOS-ADL and HOS-SS. While this association should help to better inform patients and surgeons of expected clinical outcomes, it should also encourage earlier surgeon referral and shorter trials of nonoperative treatments.

The remaining covariates negatively associated with achieving the MCID were specific to certain PROs. Older age and higher BMI were significantly associated with not achieving the MCID for HOS-ADL. Both of these risk factors have been previously established as risk factors for lower pre- and postoperative PROs; thus, one might expect that these would negatively affect the ability to achieve the MCID. Finally, the negative association between prior narcotic use and achievement of the MCID for mHHS neared significance (P = .111). This adds to the mounting evidence of the negative effects of prior narcotic use on orthopaedic surgery outcomes and should be used to temper patients' expectations after hip arthroscopy for FAI.[36,47] It is also possible that patients with preoperative narcotic use are less pain tolerant and thus more likely to continue to report pain after surgery or have more preoperative pain or sources of pain besides the FAIS itself that would be less likely to respond to FAIS decompression.

Limitations

There are several limitations to the current study, many of which are inherent to using a retrospective surgical database. First, despite the consecutive nature and high follow-up in this study, the results were those of a single high-volume fellowship-trained hip arthroscopic surgeon. Further studies should assess the generalizability of our results. Second, a number of models were analyzed with the variables in the factor analysis; however, it is possible that confounders and other nonlinear associations existed between the primary outcomes and other variables not tested. Third, this is the first study in our group to use the statistical analysis engine provided by PatientIQ. While the analysis was supervised by one of the authors formally trained in advanced statistics, future studies may be warranted to ensure that the software is capable of reproducing these models with smaller practices and different data sets. Fourth, for each model employed, we selected patients with complete observations, thereby decreasing the overall number of patients included in each model. With >1000 eligible patients, including <400 in the model introduced the potential for bias if patients with missing data had different outcomes or exposures than those with data. However, the cross-validation and model sensitivity analyses demonstrated an excellent fit for our model and reported associations/outcomes, and we believe that the study group analyzed was fairly representative of the FAI patient population. On this basis, we believe that this mitigated, in part, the effect of selection bias.

CONCLUSION

This study identified predictive variables for achieving clinically meaningful outcome after hip arthroscopy for FAIS. Patient factors including anxiety/depression, symptom duration, preoperative intra-articular injections, and high preoperative outcome scores were predictive of inability to achieve clinically meaningful outcome. These findings have important implications for shared decision-making algorithms and management of preoperative expectations after hip arthroscopy for FAI.

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