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# Validation of a Risk Calculator for Conversion of Hip Arthroscopy to Total Hip Arthroplasty in a Consecutive Series of 1400 Patients

Philip J. Rosinsky, MD, Cammille C. Go, BS, Jacob Shapira, MD, David R. Maldonado, MD, Ajay C. Lall, MD, MS, Benjamin G. Domb, MD *

*Department of Orthopedics, American Hip Institute, Des Plaines, IL*

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ABSTRACT

*Background:* A previously published calculator used age, preoperative modified Harris Hip Score, femoral anteversion, preoperative lateral center-edge angle, revision surgery, and acetabular and femoral cartilage damage to provide risk estimates for conversion rate of hip arthroscopy to total hip arthroplasty (THA). Validation for this calculator has not been established. The purpose of this study is to (1) validate the previously published hazard ratios for the predictor factors in a new cohort of hip arthroscopies with minimum 2-year follow-up and (2) determine the accuracy of the calculator at determining conversion rates to THA at 2 and 4 years of follow-up.
*Methods:* Hazard ratios for THA conversion were calculated using data between February 2008 and November 2016 and compared to the previously published results, which comprised the training set. Actual conversion to THA data was used to evaluate the accuracy of the calculator.
*Results:* Of the 1400 patients examined, THA conversion occurred in 101 (7.2%) patients at an average of 28.4 $\pm$ 22.9 months (0.2-115.8) after hip arthroscopy. The hazard ratios for the validation set compared to the training set were as follows: age 1.06 versus 1.06; modified Harris Hip Score 0.97 versus 0.98; femoral anteversion 0.99 versus 0.97; lateral center-edge angle 0.98 versus 0.93; and revision surgery 1.77 versus 2.40. Accuracy of the risk calculator at 2 years was 75% (Harrell C-statistic 0.806) and at 4 years was 73% (C-statistic 0.797).
*Conclusion:* This study found 75% and 73% accuracy at 2 and 4 years respectively in calculating risk of conversion of hip arthroscopy to THA using a previously published calculator. As this calculator relies on intraoperative data, the major benefit it provides is information regarding patient prognosis postoperatively. Furthermore, it could potentially enable the surgeon, after receiving proper surgical consent, to decide on immediate conversion to THA.
*Level of Evidence:* III, retrospective cohort.



With the rising utilization of arthroscopy to treat hip pathologies in the adult patient, many studies have examined the likelihood of treatment failure and subsequent conversion to total hip arthroplasty (THA). Despite advances in the surgical techniques, the most common reoperation after hip arthroscopy is conversion to THA, occurring in up to 10% of patients by 2 years [1–4]. Two long-term studies found conversion rates of 27% and 34% at 10 years [5,6]. Age was identified as one of the most important independent variables associated with arthroscopy failure and conversion to THA [7,8].

In patients with a history of prior hip arthroscopy who converted to THA, some studies have shown lower patient-reported outcomes (PROs), higher costs, and higher perioperative complications compared to patients undergoing primary THA [9–11]. Other studies, however, have shown comparable outcomes and complication rates when comparing these 2 groups [12,13]. With no

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* Reprint requests: Benjamin G. Domb, MD, Department of Orthopedics, American Hip Institute, 999 East Touhy Avenue, Des Plaines, IL 60018.

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particular consensus regarding the effect of prior hip arthroscopy on THA outcomes and complications, surgeons should consider the possible benefits of same-day conversion to THA. To help the decision-making process involved with this issue, Redmond et al [14] designed a time-dependent calculator to identify patients at risk of conversion to THA following hip arthroscopy. From a group of 41 preoperative and intraoperative variables, multivariate regression analyses identified 7 independent variables—age, preoperative modified Harris Hip Score (mHHS), femoral anteversion, lateral center-edge angle (LCEA), femoral and acetabular chondral damage, and primary or revision surgery—as significant. After hazard ratios (HRs) were calculated for each of the above parameters, the score for the variables could be plugged into the calculator, which provided a total point value enabling calculation of time-dependent risk of conversion to THA.

The purpose of this study was (1) to validate the previously published HRs for the predictor factors in a new cohort of hip arthroscopies with minimum 2-year follow-up and (2) to determine the accuracy of the calculator at determining conversion rates to THA at 2 and 4 years of follow-up.

## Methods

### *Patient Inclusion and Data Collection*

Data on all patients undergoing hip arthroscopy for labral tears at our institution from February 2008 to November 2016 were prospectively collected and retrospectively reviewed. All patients participated in the American Hip Institute Hip Preservation Registry. Although the present study represents a unique analysis, data on some patients in this study may have been reported in other studies. All data collection received Institutional Review Board approval.

Patients were excluded if they had undergone a previous ipsilateral arthroplasty or had previous hip condition such as avascular necrosis, ankylosing spondylitis, Ehlers-Danlos syndrome, Legg-Calve-Perthes disease, pigmented villonodular synovitis, and slipped capital femoral epiphysis. Patients in this study were defined as the validation group, whereas patients who participated in the model creation study [14] were defined as the training group (ie, patients from January 2009 to December 2011). Patients in the training group were excluded from this study.

### *Radiographic Analysis*

Radiographs were obtained for all patients prior to operative intervention. LCEA of Wiberg was measured using the anteroposterior pelvic radiograph. The angle was calculated by drawing one line from the center of one femoral head to the other, and another line from the center of the femoral head to the lateral edge of the sourcil of the acetabular rim. Although measurements were taken by multiple readers, previous interobserver reliability has been demonstrated from this institution [14]. Magnetic resonance imaging (MRI) data were reviewed to assess measurements of femoral anteversion, which was provided for 717 (51.2%) patients. The remaining missing femoral anteversion values were imputed using Markov Chain Monte-Carlo (MCMC) methods [15]. Data collected included demographic information, mHHS, intraoperative measurements of cartilage damage, and if conversion to THA occurred.

### *Surgical Indications*

Patients were indicated for arthroscopy if they had signs and symptoms of a labral tear with a positive impingement test and were unresponsive to 3 months of conservative treatment, including physical therapy, rest, cortisone injections, and nonsteroidal anti-inflammatory drugs. All surgeries were performed by the senior author (B.G.D.).

### *Statistical Analysis*

Data were analyzed using Microsoft Excel (Redmond, WA). The chi-squared and Fisher's exact tests were used to compare categorical baseline characteristics between the training and validation groups. Continuous variables were compared using *t*-tests and nonparametric variables with Mann-Whitney *U*-test and Welch test. A $P$ value <.05 was considered statistically significant.

Redmond et al [14] had previously analyzed a set of 41 potential predictors and used a multivariate, backward, stepwise Cox proportional hazard regression model to develop a time-dependent calculator for risk of conversion to THA. Seven of the 41 potential variables were found to be simultaneously associated with conversion to THA: age, preoperative mHHS, femoral anteversion, preoperative LCEA, acetabular and femoral cartilage damage grades, and primary or revision surgery status. Redmond et al's model was constructed using a training dataset of 792 subjects, 72 of whom required conversion to a THA. For validation of this model, our present study used a set of 1400 unique patients, 101 of whom converted to THA. The HR for each of the risk factors was reported and compared to the HRs calculated in Redmond et al's study.

The accuracy of the model across all time was evaluated using the Harrell C-statistic. The Harrell C-statistic integrates accuracy across a continuous timeframe, and therefore determines the general accuracy of the model [16]. The accuracy was scored based on accepted Harrell C ranges from 0.5 (poor) to 1.0 (outstanding) [17,18]. Receiver operating characteristic curves examine binary outcomes (ie, THA present or absent at that time) at specific time points, and therefore were used to determine the accuracy of conversion prediction at 2 and 4 years.

## Results

### *Demographics and Follow-Up*

Between February 2008 and November 2016, 1659 hips were eligible for 2-year follow-up and were included in the validation cohort. In total, 1400 (84.4%) cases had follow-up at minimum 2 years, with 101 (7.2%) requiring conversion to THA. A flowchart of patient selection is shown in Figure 1. Demographics of the validation cohort are included in Table 1.

### *Validation of Previously Published Hazard Ratios*

When comparing the 7 variables between the training and validation groups, significant differences were found in preoperative mHHS ($P = .04$), LCEA ($P < .001$), acetabular cartilage damage ($P < .001$), and femoral cartilage damage ($P = .0184$) (Table 2). Increased age (HR 1.06 per year), increased preoperative mHHS (HR 0.97 per point), revision surgery (HR 1.77), acetabular Outerbridge grade 4 (HR 2.48), and femoral Outerbridge grades 3 (HR 2.10) and 4 (HR 2.27) were all significant as determinants of risk of conversion to THA. Increased femoral anteversion (HR 0.99 per degree); increased LCEA (HR 0.98 per degree); acetabular Outerbridge grades 1 (HR 1.17), 2 (HR 1.04), and 3 (HR 1.43); and femoral Outerbridge grades 1 (HR 1.18) and 2 (HR 1.22) were not statistically significant (Table 3).

The conversion of patients to THA is illustrated with Kaplan-Meier estimate of survival shown in Figure 2.

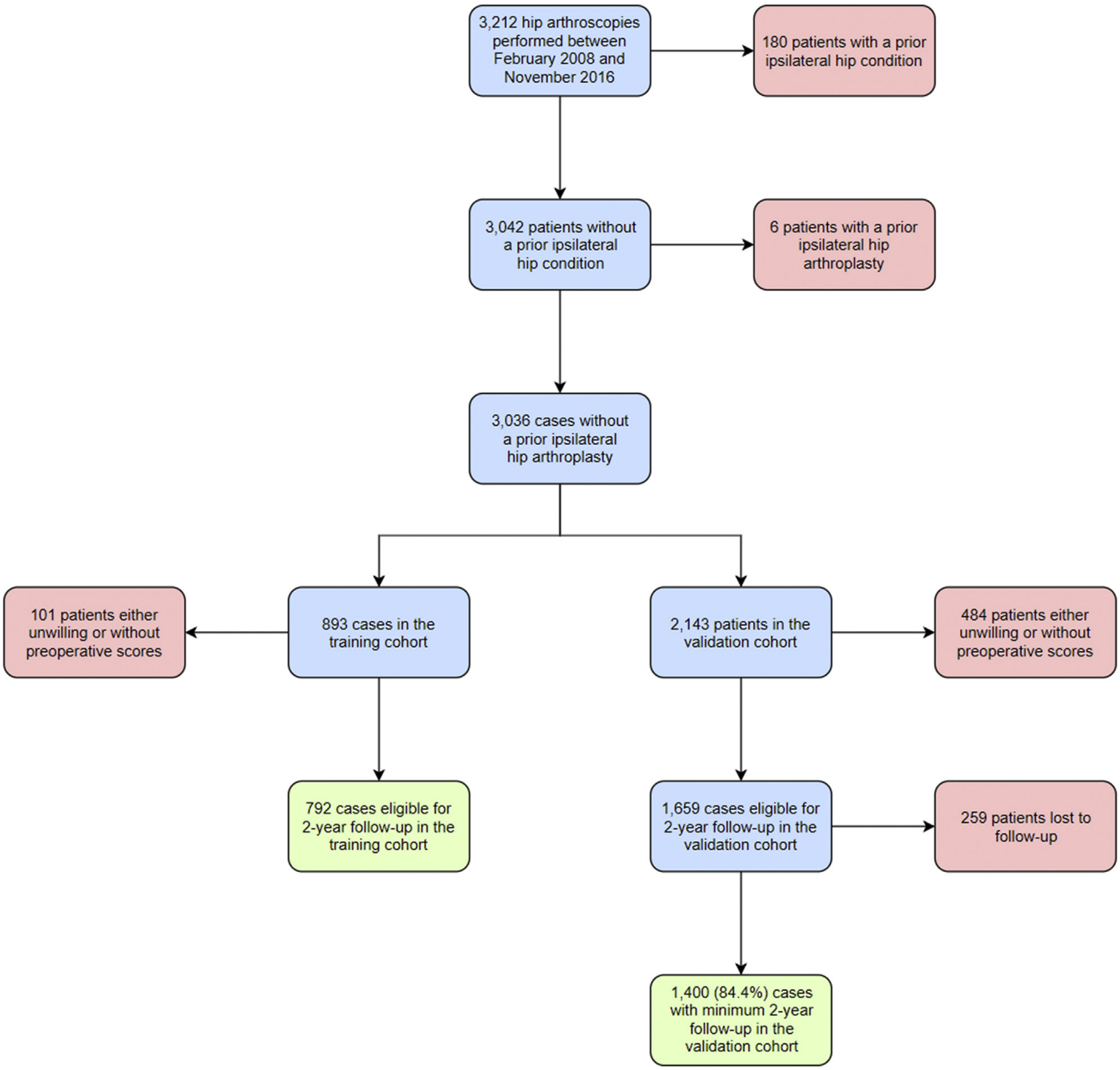


**Fig. 1.** Patient selection flowchart for validation and training cohorts.

*Accuracy of the Calculator at Determining the Conversion Rate to THA at 2 and 4 Years of Follow-Up*

The Harrell C-statistic, which provides the accuracy of the Cox model calculator at predicting conversion to THA across time, was 0.83. At 24 months postoperatively, there were 55 patients who required conversion to THA. Sensitivity and specificity at the 2-year time point were 83.6% and 67.4%, respectively, with a corresponding area under the receiver operating characteristic curve of 0.806 and accuracy of 75.5%. At 48 months postoperatively, there were 82 patients who required conversion to THA, and the model had a sensitivity of 79.3% and a specificity of 68.3%, with an area under the curve of 0.806 and an accuracy of 73.8% (Figs. 3A and 3B).

## Discussion

This study validated a previously published risk calculator designed to predict conversion to THA following hip arthroscopy. Based on 1400 unique patients, we were able to determine an excellent accuracy (Harrell C-statistic of 0.83) for the overall model [18]. Specifically, we found an accuracy of 75% at 24 months and 73% at 48 months for prediction of conversion to THA. Age at surgery, preoperative mHHS, revision surgery, acetabular Outerbridge

**Table 1**
Demographics of Study Population.

| Demographics | Validation Group (n = 1400) |
| --- | --- |
| Age (y) (range) | 37.0 ± 14.3 (13.1-75.9) |
| BMI (kg/m$^2$) (range) | 26.4 ± 5.4 (16.4-48.9) |
| Gender (female:male), n | 917:483 |
| Laterality (right:left), n | 735:665 |
| Workers' compensation claims, n (%) | 89 (6.4%) |
| Conversion to THA, n (%) | 101 (7.2%) |
| Mean time to THA (mo) (range) | 28.4 ± 22.9 (0.2-115.8) |
| Mean follow-up (mo) (range) | 42.2 ± 18.4 (24.0-120.2) |

BMI, body mass index; THA, total hip arthroplasty.

**Table 2**
Comparison of the 7 Predictor Factors Between Training and Validation Groups.

| Predictor Factors | Training Group (n = 792) | Validation Group (n = 1400) | *P* Value |
|---|---|---|---|
| Age (y) (range) | 38 ± 14 (13-76) | 36 ± 14 (13-76) | .3077 |
| Preoperative mHHS | 61 ± 17 (0-100) | 60 ± 16 (5-100) | **.0434** |
| Femoral anteversion (°) | 9 ± 10 (−21 to 10) | 9 ± 9 (−21 to 44) | .8966 |
| LCEA (°) | 29 ± 7 (11-52) | 31 ± 6 (12-55) | **.0007** |
| Revision surgery, n (%) | 81 (10.2%) | 145 (10.4%) | >.999 |
| Acetabular cartilage damage score | | | **<.001** |
| 0 | 37 (4.6%) | 219 (15.6%) | |
| 1 | 199 (25.1%) | 464 (33.1%) | |
| 2 | 294 (37.1%) | 340 (24.3%) | |
| 3 | 143 (18.0%) | 229 (16.4%) | |
| 4 | 119 (15.0%) | 148 (10.6%) | |
| Femoral cartilage damage score | | | .0184 |
| 0 | 651 (82.1%) | 1203 (85.9%) | |
| 1 | 17 (2.1%) | 10 (0.7%) | |
| 2 | 48 (6%) | 64 (4.6%) | |
| 3 | 45 (5.6%) | 71 (5.1%) | |
| 4 | 31 (3.9%) | 52 (3.7%) | |

Bold, statistically significant ($P < .05$).
LCEA, lateral center-edge angle; mHHS, modified Harris Hip Score.

grade 4, and femoral Outerbridge grades 3 and 4 were all determined to be significantly associated with risk of conversion to THA.

Failure of hip arthroscopy is defined as persistent pain, revision arthroscopy, or conversion to THA and has been attributed to poor patient selection or incorrect preoperative diagnosis [3]. Although this study does not report PROs or revision procedures, its aim is to lower rates of failure by lessening conversion rate. Registry studies have reported conversion rates at 2 years of 5.9% [3] to 12.4% [19]. In this cohort of 1400 consecutive patients, conversion to THA occurred in 55 patients by 2 years (3.9%) and in 82 patients by 4 years (5.8%). This rate is relatively low compared to other series and population-based studies; however, it is in line with evidence showing significantly lower conversion rates in high-volume centers compared to lower volume centers [3,19,20].

Previous attempts at predicting risk of conversion to THA following hip arthroscopy have been performed. Philippon et al [21] reported on patients over the age of 50 in which joint space narrowing (<2 mm) was found to be an accurate predictor of THA conversion in 81% of patients. Joint space narrowing on plain radiography is a surrogate to chondral damage which we found to be associated with a higher risk of conversion to THA. Perets et al [22] reported that patients with a body mass index of ≥30 kg/m$^2$ had a 2-fold increased risk of conversion to THA at minimum 5-year follow-up. The fact that body mass index was not found to be significant in our model may be due to the shorter time frame in this present study, which only evaluated risk up to 5 years.

Other studies have predictive models focusing on functional outcomes. Pierannunzii et al [23] created a score based on presence of arthritis, time from symptoms to surgery, and preoperative mHHS, and used this score to predict 2-year to 5-year PROs. Similarly, Stephan et al [24] attempt to develop a functional outcome prediction model based on 6 parameters: gender, pincer morphology, presence of labral tear, preoperative Hip Outcome Score-Activities of Daily Living, and the World Health Organization Quality of Life physical and psychological scores.

When compared to primary THAs, conversion of an arthroscopy to THA may have implications on post-THA PROs, costs, and perioperative complications. In 2 studies, 2-year PRO outcomes of THA after primary hip arthroscopy were assessed. Konopka et al [9] and Perets et al [10] reported lower PRO scores and a higher overall rate of complications in the conversion group when compared to a matched control group who underwent THA without a prior history of arthroscopy. In a similar study, Ryan et al [11] showed that THA performed after primary hip arthroscopy incurred higher costs

**Table 3**
Hazard Ratios of the Predictor Factors in the Training and Validation Set.

| Predictor | Unit | Hazard Ratio for Training Set (95% CI) | Hazard Ratio for Validation Set (95% CI) | *P* Value for Validation Set |
|---|---|---|---|---|
| Age at surgery | Per year | 1.06 (1.03-1.08) | 1.06 (1.04-1.07) | **<.0001** |
| Preoperative mHHS | Per unit | 0.98 (0.96-0.99) | 0.96 (0.95-0.97) | **<.0001** |
| Femoral anteversion | Per degree | 0.97 (0.94-0.99) | 0.99 (0.96-1.01) | .4504 |
| Preoperative LCEA | Per degree | 0.93 (0.89-0.97) | 0.97 (0.94-1) | .1367 |
| Revision surgery | Yes vs no | 2.40 (1.15-5.01) | 1.77 (1-3.12) | **.0482** |
| Acetabular cartilage damage grade | | | | |
| 1 vs 0 | | 0.29 (0.06-1.35) | 1.16 (0.54-2.51) | .6884 |
| 2 vs 0 | | 0.87 (0.24-3.11) | 1.03 (0.48-2.23) | .9254 |
| 3 vs 0 | | 1.8 (0.5-6.47) | 1.43 (0.65-3.14) | .3720 |
| 4 vs 0 | | 1.95 (0.54-7.04) | 2.48 (1.16-5.28) | **.0182** |
| Femoral cartilage damage grade | | | | |
| 1 vs 0 | | 0.59 (0.08-4.42) | 1.18 (0.15-8.85) | .8695 |
| 2 vs 0 | | 2.23 (1.11-4.46) | 1.21 (0.62-2.36) | .5606 |
| 3 vs 0 | | 2.17 (1.11-4.23) | 2.09 (1.15-3.8) | **.0143** |
| 4 vs 0 | | 2.96 (1.34-6.52) | 2.26 (1.09-4.69) | **.0272** |

Bold, statistically significant ($P < .05$).
CI, confidence interval; LCEA, lateral center-edge angle; mHHS, modified Harris Hip Score.

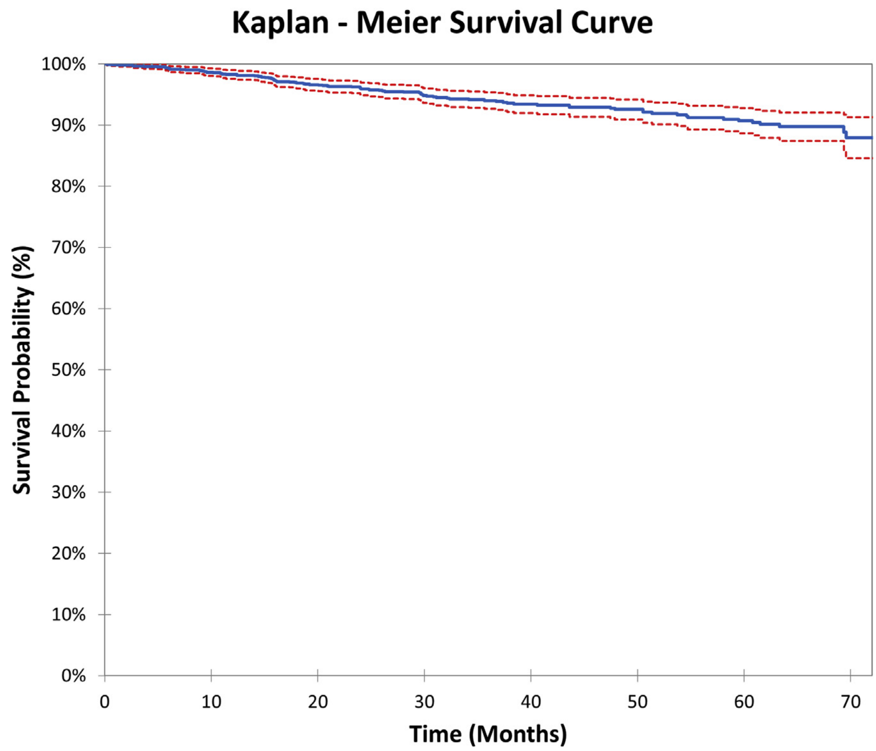


**Fig. 2.** Kaplan-Meier survival curve for patients who underwent hip arthroscopy. Red lines represent 95% confidence intervals.

than primary THA alone. Thus, one may infer that the literature is primed for predictive models able to identify patients with a higher risk of failed hip arthroscopy, who may eventually convert to THA at a later date in an attempt to seek relief of pain and dysfunction. In order to optimize patient care, an individualized approach is needed that accounts for patient unique parameters. The model created by Redmond et al is a step toward achieving a better prediction of patient outcomes and survivorship of the native joint following hip preservation surgery.

An aim of this study is to validate Redmond's model. Using the Harrell C-statistic, we were able to determine an accuracy of 0.83 for the overall model [18]. Studies in other fields of medicine have also reported similar C-statistics as favorable when validating predictor models. In a multicenter study, Mehta et al [25] classified a C-statistic of 0.82 as good for validation of a model to predict tumor recurrence after liver transplantation. For validation of a model to predict short-term risk of death in patients aged 65 or more, Hippisley-Cox and Coupland [26] classified a C-statistic of 0.85 as very good in a cohort of 1.5 million patients. Deo et al classified a C-statistic of 0.745 and 0.820 as good to excellent for validation of a model predicting sudden cardiac death for the general population.

One limitation of Redmond's calculator [14] is the reliance on an intraoperative measurement of cartilage damage, as opposed to preoperative measurements such as Tönnis grade or the delayed gadolinium-enhanced MRI of cartilage. Although this therefore limits the applicability of the model in the preoperative assessment, the calculator may still prove useful in determining risk of failure at the time of surgery. One possible application is in cases which are perceived as borderline arthritic, where after appropriate informed consent is obtained prior to surgery, the option of immediate conversion to a THA will be available after diagnostic hip arthroscopy based on surgeon discretion. A future calculator should try to base the prediction of failed hip arthroscopy or PROs on strictly preoperative variables. This type of predictive model would allow for a more accurate discussion of risks and benefits during the informed consent process between physicians and patients. Ultimately, this level of accuracy would help determine expected prognosis and likely prevent surgery in cases where chances of success are predicted to be low.

### *Strengths*

There are a number of strengths with this validation study. First, this study includes a large sample size of 1400 consecutive patients in the validation group, all with prospective data collection. Next, the usage of the Harrell C-statistic, in addition to the area under the curve, allows analysis of the overall accuracy of the model at all time points. Finally, procedures were conducted by a single, high-volume hip arthroscopy surgeon (B.G.D.), minimizing variability.

### *Limitations*

This validation study has a number of limitations. First, the study relied on patient data from the same single-center, high-volume research institute which was used to create the model. Thus, the applicability of this calculator to other surgical centers needs to be assessed. Next, radiographic measurements were read by several orthopedic fellows, introducing the possibility of interobserver bias. In addition, of the 7 parameters used within the model, one of the parameters was femoral anteversion. Not all patients in this study had MRI data available, and therefore the remaining information was imputed via MCMC simulation [15]. Imputed data could have led to a reduction in the accuracy of our results; however, the MCMC method is a valid, reproducible statistical method well established in the literature and is favorable to omitting individuals with missing data as it increases power and decreases bias [27–30]. Finally, this validation was performed on a

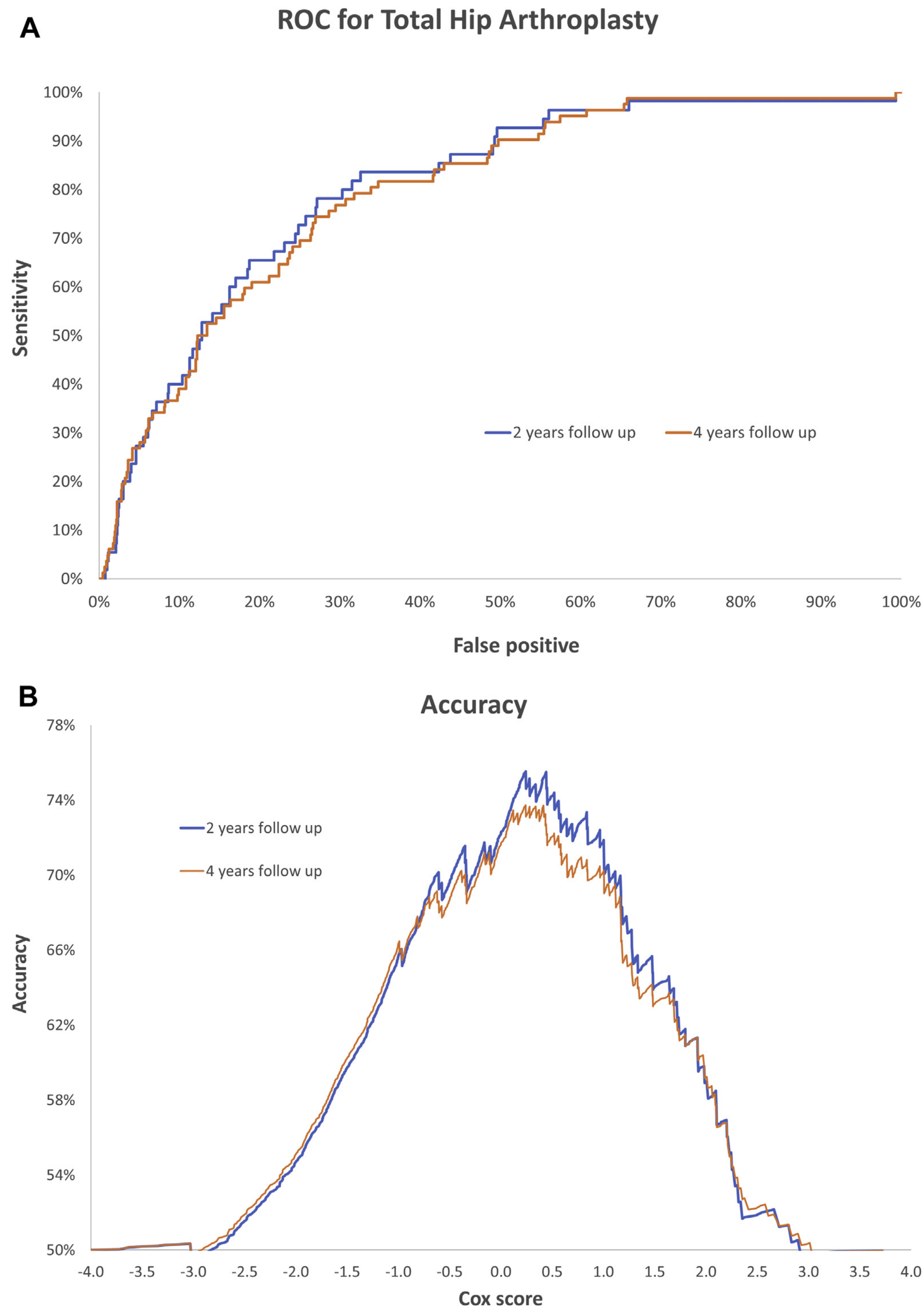


**Fig. 3.** (A) The graph shows the ROC curve for THA patients at 2 and 4 y. (B) The accuracy of model at calculating risk of conversion to THA for THA patients at 2 and 4 y is shown in the graph. ROC, receiver operating characteristic curve.

cohort of patients with only midterm follow-up. The accuracy of this prediction at longer follow-up remains unknown.

## Conclusion

This study found 75% and 73% accuracy at 2 and 4 years respectively in calculating risk of conversion of hip arthroscopy to THA using a previously published calculator. As this calculator relies on intraoperative data, the major benefit it provides is information regarding patient prognosis postoperatively. Furthermore, it could potentially enable the surgeon, after receiving proper surgical consent, to decide on immediate conversion to THA.

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