Original Article

Procedure Type and Preoperative Patient-Reported Outcome Metrics Predict Variation in the Value of Hip Arthroscopy for Femoroacetabular Impingement

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Purpose: To characterize variation in the value of hip arthroscopy for femoroacetabular impingement and explore associations between value and patient-specific demographic characteristics, comorbidities, preoperative patient-reported outcome measures (PROMs), and intraoperative variables. **Methods:** We included all patients aged 18 years or older who underwent primary arthroscopic acetabular labral repair or debridement between 2015 and 2020 with minimum 2-year follow-up. The exclusion criteria were hip dysplasia, advanced hip osteoarthritis (TÖnnis grade >1), or unreconcilable documenting errors. Value was calculated by dividing 2-year postoperative International Hip Outcome Tool 33 scores by time-driven activity-based costs. To protect the confidentiality of internal hospital cost data, the study average for value was normalized to 100. Multivariable linear mixed-effects models were used to identify factors underlying variation in value. **Results:** This study included 161 patients. There were 76 women (47.2%) and 85 men, with a mean age of 36.0 years (standard deviation [SD], 10.9 years) and mean body mass index (BMI) of 25.8 (SD, 4.3). Most patients were white (92.5%), were not Hispanic (93.8%), and were commercially insured (92.5%). Preoperatively, 57.1% of hips were classified as Tönnis grade 1 (57.1%) whereas the remainder were grade 0. The normalized value of hip arthroscopy ranged from 25.4 to 216.4 (mean ± SD, 100 ± 38.4), with a 3.0-fold variation between patients in the 10th and 90th percentiles. Higher value was significantly associated with Tönnis grade 0 (12.2-point increase, $P = .025$), no prior contralateral hip arthroscopy (17.3-point increase, $P = .039$), higher preoperative PROMs (0.52-point increase per 1-unit increase, $P < .001$), and no bone marrow aspirate concentrate or microfracture (33.8-point increase, $P < .001$). Value was also significantly associated with osteoplasty type and labral treatment technique ($P < .05$ for both). In contrast, operative year, age, sex, BMI, race, ethnicity, Outerbridge grade, and American Society of Anesthesiologists score were not independently associated with value. A model incorporating these factors as fixed effects and the surgery center as a random effect explained 42.3% of the observed variation in value. Sensitivity analyses revealed that value drivers may vary slightly across PROMs. **Conclusions:** This study revealed wide variation in the value of hip arthroscopy that was most strongly explained by osteoplasty type, labral management technique, and preoperative PROMs. In contrast, patient demographic characteristics such as age, sex, and BMI contributed minimal independent variability. **Level of Evidence:** Level IV, economic and decision analysis.

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As health care costs in the United States continue to rise, often outpacing improvements in quality, value-based health care has received growing attention—particularly within orthopaedics.[1-4] This framework revolves around "value," defined as patient health outcomes achieved per dollar spent.[5-8] As such, value improvement efforts can be achieved by improving outcomes, reducing costs, or both.

Despite the growing use of hip arthroscopy for treating labral pathologies and femoroacetabular impingement (FAI), the extent and drivers of variation in its value remain unknown.[9-11] Moreover, previous efforts to characterize the value of hip arthroscopy have focused exclusively on costs, precluding commentary on whether cost drivers may be clinically justified from a value-based perspective.[12,13] Such studies have revealed wide patient-to-patient cost variation most strongly associated with labral management and osteoplasty technique, the operating surgeon and surgery center, and operating room consumables and implants.[12,13] However, cost reduction without regard to outcomes is inadvisable and often self-defeating; thus, there is a need for a value-based analysis of hip arthroscopy that integrates outcomes with costs.

Time-driven activity-based costing (TDABC) is an accounting methodology that measures costs by synthesizing the quantity of resources expended with their per-unit costs.[14-16] This technique, which has been shown to outperform traditional hospital costing methods, has recently emerged as the gold-standard methodology within orthopaedics[17-21]; however, its use to investigate the variation and drivers of patient value after hip arthroscopy has been limited.

The purposes of this study were to characterize variation in the value of hip arthroscopy for FAI and explore associations between value and patient-specific demographic characteristics, comorbidities, preoperative patient-reported outcome measures (PROMs), and intraoperative variables. We hypothesized there would exist wide variation (i.e., >2.0-fold) in value between cases in the 10th and 90th percentiles and that 30% to 40% of this variation would be explained by differences in patient characteristics and intraoperative variables.[22]

Methods

Patient Sample and Study Design

The prospectively collected data of patients who underwent hip arthroscopy between June 2015 and September 2020 performed by a single fellowship-trained surgeon (S.D.M.) were retrospectively reviewed. The patient inclusion criteria consisted of the following: age 18 years or older; primary hip arthroscopy for the treatment of symptomatic labral tears due to FAI between June 2015 and September 2020; and complete preoperative and 2-year postoperative PROMs. Patients were excluded if they showed radiographic evidence of hip dysplasia (lateral center-edge angle <20°) or advanced hip osteoarthritis (Tönnis grade >1) or exhibited unreconcilable discrepancies in their medical records (e.g., transfer to the post-anesthesia care unit before incision closure or use of ≥10 suture anchors).[23] This study received institutional review board approval (Nos. 2019P002191, 2013P001442/BWH, and 2022P002843).

During the study period, all patients underwent a standardized, stepwise preoperative evaluation for hip pain. This included hip and pelvis radiographs (anteroposterior pelvic and Dunn lateral views) and a comprehensive physical examination with provocation testing for labral pathology and impingement-related symptoms (e.g., pain and/or limited range of motion in flexion, adduction, and internal rotation or flexion, abduction, and external rotation).[24,25] Patients with positive clinical and radiographic findings underwent further evaluation with magnetic resonance imaging or magnetic resonance arthrography, as well as diagnostic intra-articular hip injections combining a local anesthetic and low-dose corticosteroid. All patients completed a minimum 3-month trial of nonoperative management, including formal physical therapy.[26] Patients with persistent hip pain despite these interventions and evidence of labral tears were offered hip arthroscopy and were eligible for enrollment in this study.[27]

Time-Driven Activity-Based Costing

TDABC was performed as described previously,[12] consistent with guidelines established by Kaplan and Anderson[14] and other experts.[16,28-31] In brief, applying TDABC entails constructing process maps that include all activities involved in the care pathway; quantifying the time and resources required for each activity; multiplying the quantity of each resource expended by its per-unit cost; and summing these products to calculate the total cost of care on a case-specific basis. With guidance from Avant-garde Health (Boston, MA), process maps were developed by directly observing hip arthroscopy cases and interviewing physicians, nurses, and other health care professionals. Given the extensive modeling and assumptions required to incorporate indirect or structural costs, our analysis focused on direct personnel and supply costs.[32-34]

The hip arthroscopy care cycle was stratified into preoperative, intraoperative, and postoperative phases (Appendix Tables 1-3). For standard components of the care pathway (e.g., check-in, meeting the surgical team, and being transported to the operating room), durations were estimated based on interviews and direct observations. Conversely, components likely to vary between patients (e.g., operative time, type of support personnel, and supply costs) were directly extracted from electronic health records (EHRs), which provide the most accurate and credible source data available.[16,31,35] Supply costs were also derived from EHRs and reflect the actual purchase price of consumables, excluding profit margins. Labor costs per minute (i.e., capacity cost rates [CCRs]) were determined by Avant-garde Health based on institutional averages. Specifically, CCRs were calculated for each professional category by dividing the mean total salary (including salary, taxes, training, and other indirect support expenses), obtained via institutional financial data, by the mean workload contracted annually (measured in minutes).[30] CCRs were then multiplied by the time required for each task or activity on a case-specific basis to generate labor costs (Microsoft Excel; Microsoft, Redmond, WA). Finally, to calculate the total cost of the care cycle, labor costs and supply costs were summed on a case-specific basis. Of note, all cases showing costs in the upper and lower fifth percentiles were manually reviewed for anomalies; records with clear discrepancies were excluded.

Data Collection and Outcomes

Patient characteristics including age, body mass index (BMI), sex, race, ethnicity, American Society of Anesthesiologists score, anxiety, depression, previous contralateral hip arthroscopy, and insurance coverage were manually extracted from EHRs. PROMs were collected at baseline and 2 years postoperatively and included the International Hip Outcome Tool 33 (iHOT-33) score, Hip Outcome Score—Activities of Daily Living (HOS-ADL), and Hip Outcome Score—Sports Subscale (HOS-SS). The primary outcome of this study was normalized patient value, which was calculated by dividing 2-year postoperative iHOT-33 scores by time-driven activity-based costs and multiplying by an undisclosed constant to set the study mean to 100, as described further in the "Statistical Analysis" section. In addition, sensitivity analyses also explored value calculated using the HOS-ADL and HOS-SS via a similar normalization process. Granular case-specific features were determined using operative notes and included surgery center, provider team, and type of procedure. Case-specific timestamps and supply costs were also extracted directly from EHRs manually or using Care Measurement software (Avant-garde Health).

Abbreviated Surgical Technique

After undergoing intubation and sedation with general anesthesia, all patients were positioned supine on a hip distraction table (Advanced Supine Hip Positioning System; Smith & Nephew, Andover, MA) with a well-padded perineal post. The anterolateral portal was created using fluoroscopic guidance and intra-articular fluid distention, and the anterior, midanterior, and Dienst portals were subsequently placed under direct arthroscopic visualization.[36] Puncture capsulotomy was used to resolve intra-articular pathologies while the native hip anatomy and biomechanics were preserved.[37,38] Additionally, electrocautery and traction were used intermittently to minimize intra-articular temperatures and perineal nerve complications, respectively.[39,40]

After inspection of osseous deformities and damage to the labrum, chondrolabral junction, and articular cartilage, acetabular recession and acetabuloplasty were performed to remove pincer lesions without violating the chondrolabral junction.[41] If feasible, simple labral repair was subsequently performed using 2.3-mm bioabsorbable composite Osteoraptor suture anchors (Smith & Nephew), whereas labral repair with augmentation via capsular autograft (i.e., "labral augmentation") was completed in cases of complex tears, hypoplastic labra, and/or degenerative labral tissue.[42-44] The sutures were subsequently tied down using dynamic tensioning simultaneous with traction release to promote formation of an anatomic, "inround" repair and avoid labral eversion.[40,43] Traction was then fully released, and dynamic examination along with direct visualization from the peripheral compartment was performed to test for functional impingement and evaluate the labral seal. Finally, as indicated, any impinging cam lesions were resected with the hip flexed to approximately 45°. All patients were instructed to follow the same 5-phase, patient-guided rehabilitation program, as described previously.[26]

It is worth noting that the preferred method of the senior surgeon (S.D.M.) for addressing full-thickness chondral flaps, chondrolabral junction breakdown, and/or focal lesions of Outerbridge grade 2 or higher changed during the study period. Specifically, microfracture was carried out from June 2015 to November 2016 whereas a standardized method of bone marrow aspirate concentrate (BMAC) augmentation was used from December 2016 to September 2020.[45-49] No other significant variations in surgical technique occurred during the study period.

Statistical Analysis

To protect the confidentiality of internal hospital cost data, all measures of patient value were normalized to set the study average for each metric to 100. For example, if mean un-normalized patient value for the iHOT-33 instrument equaled 0.5 for the study sample, patient value (i.e., iHOT-33 score divided by cost) would be multiplied by 200 for each patient. Of note, this normalization preserved relative values and had no impact on subsequent statistical analysis.[50] Descriptive statistics for continuous and categorical variables were presented as mean (standard deviation

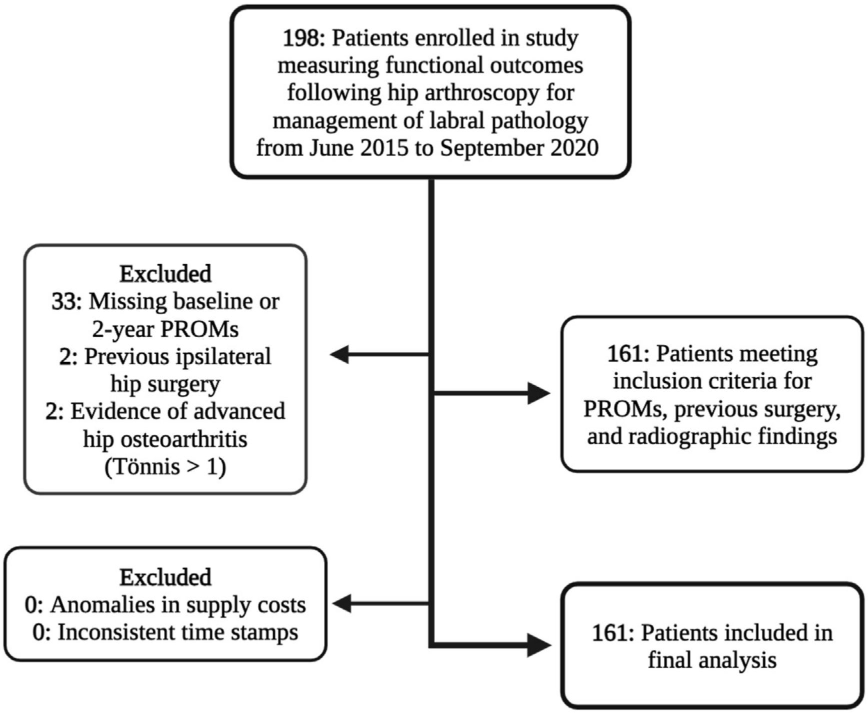

Fig 1. Flowchart detailing patient selection process. (PROM, patient-reported outcome measure.)

[SD]) and frequency (percentage). Given low counts of some categorical variables (e.g., Asian race or Outerbridge grade 0), some groups were redefined for the unadjusted and adjusted analyses (e.g., Outerbridge grade 0-2 vs grade 3-4). In unadjusted analyses, value was compared among categorical variables using unpaired *t* tests or 1-way analysis of variance, as appropriate, and correlations between value and continuous variables were measured with Pearson correlation coefficients (*r*). To account for non-independence of observations from different surgery centers, multivariable linear mixed-effects models (with the surgery center included as a random intercept) were used to identify factors independently associated with value.[51,52] Model variables were selected based on unadjusted analyses, clinical judgment, previous literature, and information criteria (i.e., the Akaike information criterion and Bayesian information criterion).[53] The statistical significance of model parameters was determined using likelihood-ratio tests.[54] Marginal and conditional coefficients of determination were calculated using methods published by Nakagawa et al.[55,56] Additionally, sensitivity analyses were performed to evaluate whether distinct value drivers emerged across different PROMs. Specifically, multivariable mixed-effects models were repeated as described earlier, except value was calculated using the HOS-ADL and HOS-SS. All analyses were performed with R (version 4.2.1; R Foundation for Statistical Computing, Vienna, Austria), and $P < .05$ was considered significant.

Results

Participants

A total of 161 subjects were included (Fig 1). There were 76 women (47.2%) and 85 men, with a mean age of 36.0 years (SD, 10.9 years) and mean BMI of 25.8 (SD, 4.3). Most patients were white (92.5%), were not Hispanic (93.8%), and were commercially insured (92.5%). Preoperatively, 57.1% of hips were classified as Tönnis grade 1 (57.1%) whereas the remainder were grade 0. The mean preoperative iHOT-33 score, HOS-ADL, and HOS-SS were 40.1 (SD, 17.9), 70.0 (SD, 18.9), and 41.4 (SD, 23.8), respectively; the mean postoperative iHOT-33 score, HOS-ADL, and HOS-SS were 76.1 (SD, 21.4), 90.1 (SD, 11.5), and 76.6 (SD, 24.0), respectively. Regarding intraoperative findings, 67.7% of hips showed Outerbridge grade 3 or 4 lesions, and the mean labral tear size was 75.5° (SD, 23.1°). Additional patient characteristics and intraoperative findings are summarized in Table 1.

Unadjusted Value Analyses

The normalized value of hip arthroscopy per patient ranged from 25.4 to 216.4 (mean ± SD, 100 ± 38.4), with a 3.0-fold variation between patients in the 10th and 90th percentiles. Patient characteristics associated with significantly higher value were older age ($r = 0.18$, $P = .020$), female sex (109.0 vs 91.9, $P = .004$), and higher preoperative iHOT-33 score ($r = 0.16$, $P = .043$; Table 2). Regarding procedure type, higher value was significantly associated with labral debridement (155.7

Table 1. Demographic Characteristics, Comorbidities, and Operative Characteristics of Patients in Study (N = 161)

Variable	Mean (SD) or No. (%)
Year	
2015	9 (5.6)
2016	9 (5.6)
2017	21 (13.0)
2018	62 (38.5)
2019	33 (20.5)
2020	27 (16.8)
Age, yr	36.0 (10.9)
Body mass index	25.8 (4.3)
Sex	
Female	76 (47.2)
Male	85 (52.8)
Race	
Asian	5 (3.1)
Black or African American	2 (1.2)
White	149 (92.5)
Other	5 (3.1)
Ethnicity	
Hispanic or Latino	10 (6.2)
Not Hispanic or Latino	151 (93.8)
ASA score	
1	85 (52.8)
2	76 (47.2)
Anxiety	13 (8.1)
Depression	16 (9.9)
Osteoplasty type	
Acetabuloplasty	77 (47.8)
Femoroplasty	9 (5.6)
Both	70 (43.5)
Neither	5 (3.1)
Labrum procedure	
Labral augmentation*	141 (87.6)
Debridement	7 (4.3)
Simple repair	13 (8.1)
Previous contralateral surgery	12 (7.5)
BMAC or microfracture	103 (64.0)
Labral tear size, °	75.5 (23.1)
No. of suture anchors	
0-2	56 (34.8)
3	93 (57.8)
4-5	12 (7.5)
Traction time, min	71.7 (12.0)
Tönnis grade	
0	69 (42.9)
1	92 (57.1)
Outerbridge grade	
0	2 (1.2)
1	6 (3.7)
2	44 (27.3)
3	80 (49.7)
4	29 (18.0)
Organization	
Surgery center 1	90 (55.9)
Surgery center 2	43 (26.7)
Surgery center 3	28 (17.4)
Insurance	
Commercial	149 (92.5)
Government	12 (7.5)
Assistance	
Resident	2 (1.2)
Fellow	48 (29.8)
Physician's assistant	49 (30.4)
Multiple	40 (24.8)
None	22 (13.7)
Preoperative iHOT-33 score	40.1 (17.9)
Preoperative HOS-ADL	70.0 (18.9)
Preoperative HOS-SS	41.4 (23.8)

(continued)

Table 1. Continued

ASA, American Society of Anesthesiologists; BMAC, bone marrow aspirate concentrate; HOS-ADL, Hip Outcome Score−Activities of Daily Living; HOS-SS, Hip Outcome Score−Sports Subscale; iHOT-33, International Hip Outcome Tool 33; SD, standard deviation.

*Labral augmentation refers to labral repair with augmentation via capsular autograft.[43,44]

for debridement [n = 7] vs 110.2 for simple repair [n = 13] vs 96.3 for labral augmentation [n = 141], $P < .001$), no osteoplasty (163.3 vs 86.5 for femoral acetabuloplasty, $P < .001$), no BMAC or microfracture (124.4 vs 86.3, $P < .001$), and fewer suture anchors (e.g., 123.0 for 0-2 anchors vs 69.8 for 4-5 anchors; $P < .001$) (Table 3). Additionally, associated with lower value were labral tear size ($r = -0.33$, $P < .001$), traction time ($r = -0.40$, $P < .001$), and year of operation ($r = -0.18$, $P = .024$). Significant variation in value was also observed between surgery centers (e.g., 93.8 for center 1 vs 111.7 for center 2; $P < .001$). Value was not found to be significantly associated with BMI, race, ethnicity, American Society of Anesthesiologists score, anxiety, depression, previous contralateral hip arthroscopy, Tönnis grade, Outerbridge grade, insurance coverage, or provider team. Additional estimates and all 95% confidence intervals (CIs) are presented in Tables 2 and 3. Visual representations of value with continuous variables are depicted in Figure 2.

Adjusted Value Analysis

A mixed-effects model was implemented to explore independent associations between value and selected characteristics. Consistent with unadjusted analyses, preoperative iHOT-33 score, type of osteoplasty, labral management technique, and use of BMAC or microfracture significantly explained variation in value ($P < .05$ for all) whereas Outerbridge grade did not ($P = .27$). It is interesting to note that although value varied across age, sex, and year of operation in the unadjusted analyses, these characteristics were not found to be independently associated with value in the adjusted model. The opposite was observed for Tönnis grade (mean difference for Tönnis grade 1 relative to grade 0, −12.15 [95% CI, −22.00 to −2.30]; $P = .025$) and previous contralateral hip arthroscopy (mean difference for previous contralateral surgery, −17.31 [95% CI, −34.94 to 0.31]; $P = .039$), which emerged as independent sources of value in the adjusted analysis. Mean effect sizes and 95% CIs for all characteristics are

Table 2. Unadjusted Analyses Exploring Associations Between Preoperative Patient Characteristics and Value

Variable	Normalized Value (95% CI)	*P* Value
Year	−0.18 (−0.32 to −0.02)	.024*
Age	0.18 (0.03 to 0.33)	.020*
Body mass index	0.02 (−0.13 to 0.18)	.78
Sex		.004*
Female	109.0 (99.5 to 118.5)	
Male	91.9 (84.7 to 99.1)	
Race		.50
Not white	92.7 (69.6 to 115.8)	
White	100.6 (94.3 to 106.8)	
Ethnicity		.068
Hispanic or Latino	78.6 (56.9 to 100.2)	
Not Hispanic or Latino	101.4 (95.2 to 107.6)	
ASA score		>.999
1	100.0 (92.3 to 107.7)	
2	100.0 (90.5 to 109.4)	
Anxiety		.84
Yes	102.1 (74.4 to 129.8)	
No	99.8 (93.7 to 106.0)	
Depression		.30
Yes	90.5 (70.4 to 110.6)	
No	101.0 (94.7 to 107.4)	
Previous contralateral surgery		.059
Yes	81.4 (61.1 to 101.7)	
No	101.5 (95.3 to 107.7)	
Tönnis grade		.19
0	104.6 (96.3 to 113.0)	
1	96.5 (88.1 to 105.0)	
Organization		<.001*
Surgery center 1	93.8 (87.3 to 100.3)	
Surgery center 2	111.7 (98.5 to 125.0)	
Surgery center 3	101.8 (83.1 to 120.5)	
Insurance		.87
Commercial	100.1 (94.2 to 106.1)	
Government	98.2 (62.5 to 133.9)	
Preoperative iHOT-33 score	0.16 (0.00 to 0.31)	.043*
Preoperative HOS-ADL	0.16 (0.00 to 0.30)	.046*
Preoperative HOS-SS	0.14 (−0.01 to 0.29)	.067

NOTE. Data are presented as normalized cost or Pearson correlation coefficient (95% CI).

ASA, American Society of Anesthesiologists; CI, confidence interval; HOS-ADL, Hip Outcome Score−Activities of Daily Living; HOS-SS, Hip Outcome Score−Sports Subscale; iHOT-33, International Hip Outcome Tool 33.

*Statistically significant.

Table 3. Unadjusted Analyses Exploring Associations Between Intraoperative Patient Characteristics and Value

Variable	Normalized Value (95% CI)	*P* Value
Osteoplasty type		<.001*
Acetabuloplasty	106.8 (98.4, 115.1)	
Femoroplasty	111.9 (65.8 to 158.1)	
Both	86.5 (79.6 to 93.4)	
Neither	163.3 (108.3 to 218.3)	
Labrum procedure		<.001*
Labral augmentation†	96.3 (90.4 to 102.1)	
Debridement	155.7 (97.9 to 213.6)	
Simple repair	110.2 (89.4 to 131.1)	
Labral tear size, °	−0.33 (−0.46 to −0.19)	<.001*
BMAC or microfracture		<.001*
Yes	86.3 (81.0 to 91.6)	
No	124.4 (113.0 to 135.7)	
No. of suture anchors		<.001*
0-2	123.0 (111.6 to 134.3)	
3	90.1 (84.0 to 96.1)	
4-5	69.8 (53.0 to 86.6)	
Traction time, min	−0.40 (−0.52 to −0.26)	<.001*
Outerbridge grade		.71
0-2	101.7 (91.5 to 111.8)	
3-4	99.2 (91.7 to 106.7)	
Assistance		.20
Resident or fellow	92.9 (83.1 to 102.8)	
Physician's assistant	98.4 (86.6 to 110.2)	
Multiple	101.6 (88.7 to 114.5)	
None	116.6 (101.9 to 131.4)	

NOTE. Data are presented as normalized cost or Pearson correlation coefficient (95% CI).

BMAC, bone marrow aspirate concentrate; CI, confidence interval.

*Statistically significant.

†Labral augmentation refers to labral repair with augmentation via capsular autograft.[43,44]

reported in Table 4. A model incorporating these factors as fixed effects and surgery center as a random effect explained 42.3% of the observed variation in value. Surgery center accounted for only 0.5% of the model's explanatory power.

Sensitivity Analyses

To assess the robustness of these findings across different outcome measures, the adjusted analysis was repeated with value calculated using the HOS-ADL and HOS-SS (Tables 5 and 6). The only results that varied from those of the primary adjusted analysis were as follows: Previous contralateral hip arthroscopy no longer explained value in the HOS-ADL ($P = .071$) or HOS-SS ($P = .80$) models; higher Outerbridge grade was associated with lower value in the HOS-ADL model (mean difference, 3.73-point decrease per grade; $P = .35$); and neither Tönnis grade ($P = .12$) nor labral management technique ($P = .80$) explained value in the HOS-SS model.

Discussion

In this study, the most important finding is the wide variation in the value of hip arthroscopy that was most strongly associated with osteoplasty type, labral management technique, and preoperative PROMs. Specifically, normalized value—defined in this study as 2-year PROMs divided by TDABC costs—was found to vary by 3.0-fold between patients in the 10th and 90th percentiles.[1,6] Multivariable modeling revealed that patient characteristics and intraoperative variables explained 42.3% of the observed variation in value, with preoperative PROMs, previous surgery, Tönnis grade, osteoplasty type, and labral management emerging as the strongest predictors. These findings

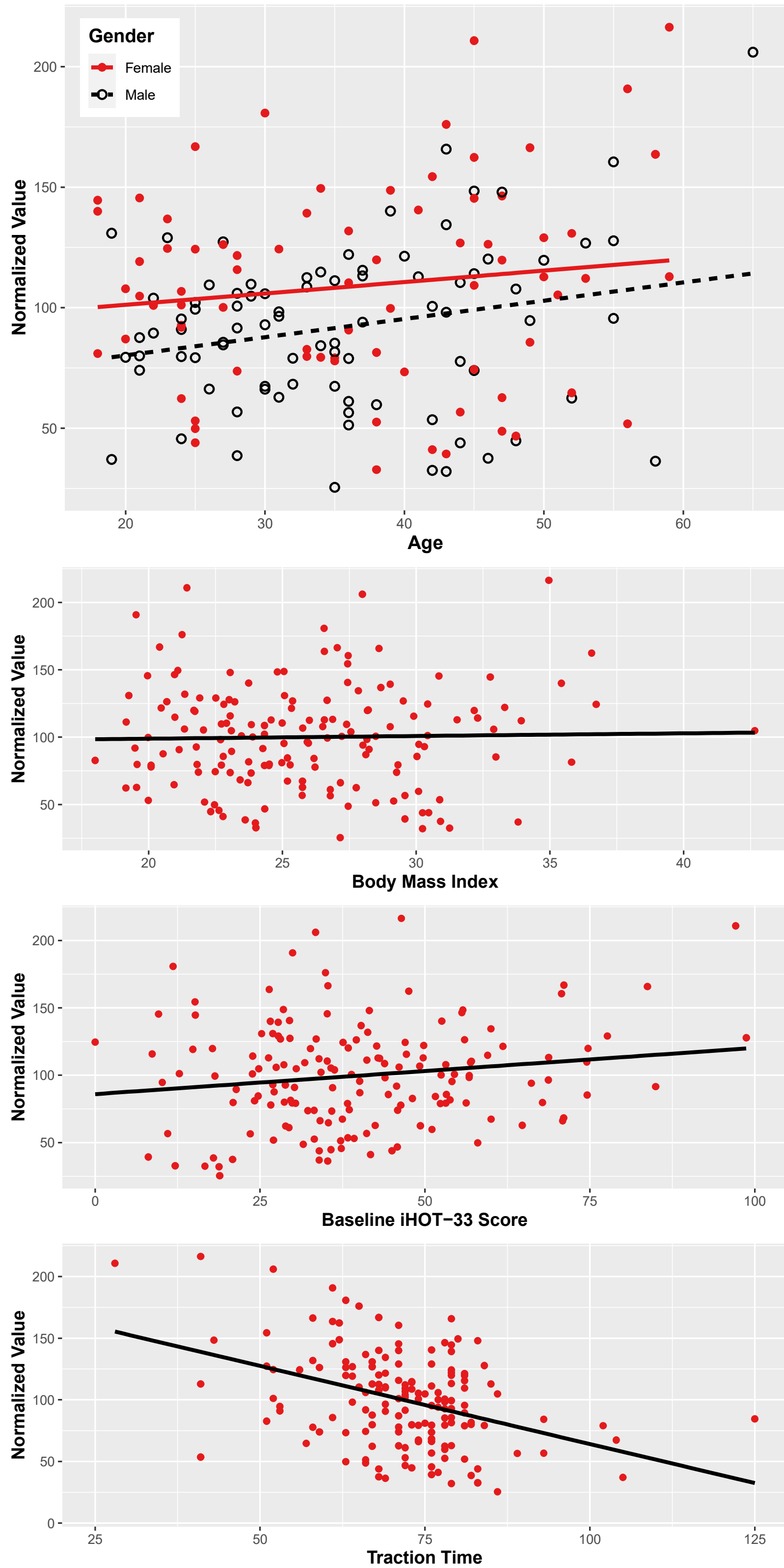

Fig 2. Scatter plots showing variation in value in relation to age (stratified by sex), body mass index, baseline International Hip Outcome Tool 33 (iHOT-33) score, and traction time.

Table 4. Multivariable Mixed-Effects Model Evaluating Characteristics Underlying Variation in Value

Variable	Mean Difference	95% CI Lower	95% CI Upper	*P* Value*
Patient characteristics				
Age, per 1-yr increase	0.19	−0.34	0.72	.84
Male sex	−5.37	−16.23	5.49	.52
Previous contralateral surgery	−17.31	−34.94	0.31	.039†
Preoperative iHOT-33, per 1-point increase	0.52	0.25	0.80	<.001†
Preoperative or intraoperative findings				
Outerbridge grade	−3.93	−10.03	2.17	.27
Tönnis grade 1‡	−12.15	−22.00	−2.30	.025†
Case-specific factors				
Year, per 1-yr increase	2.60	−1.81	7.00	.52
Acetabuloplasty or femoroplasty§	11.18	0.32	22.03	<.001†
No osteoplasty§	57.59	25.87	89.31	
Labral debridement‖	21.60	−4.13	47.34	.029†
Simple labral repair‖	−3.39	−20.91	14.12	
BMAC or microfracture	−33.77	−45.40	−22.14	<.001†

NOTE. This model also included surgery center as a random intercept, with marginal $R^2 = 0.420$ and conditional $R^2 = 0.423$.
BMAC, bone marrow aspirate concentrate; CI, confidence interval; iHOT-33, International Hip Outcome Tool 33.
**P* values calculated using likelihood-ratio tests.
†Statistically significant.
‡Reference category: Tönnis grade 0.
§Reference category: acetabular femoroplasty.
‖Reference category: labral repair with augmentation via capsular autograft.[43,44]

have implications for value optimization, risk adjustment, and the measurement of patient value.

We found that value varies widely between patients: We documented 380% variation between patients in the 10th and 90th percentiles for value. This result is striking for 2 reasons. First, we analyzed a relatively homogeneous sample of patients operated on by a single fellowship-trained orthopaedic surgeon (S.D.M.) who had completed well over 1,000 cases before the initiation of this study. Thus, the variation in value across the United States, including both high- and low-volume surgeons, is likely substantially higher.[57]

Table 5. Multivariable Mixed-Effects Model Evaluating Characteristics Underlying Variation in Value: Modified HOS-ADL Analysis

Variable	Mean Difference	95% CI Lower	95% CI Upper	*P* Value*
Patient characteristics				
Age, per 1-yr increase	−0.01	−0.33	0.30	.94
Male sex	−4.23	−10.56	2.11	.19
Previous contralateral surgery	−9.55	−19.92	0.83	.071
Preoperative HOS-ADL, per 1-point increase	0.24	0.09	0.39	<.001†
Preoperative or intraoperative findings				
Outerbridge grade	−3.73	−7.19	−0.27	.035†
Tönnis grade 1‡	−6.94	−12.66	−1.22	.018†
Case-specific factors				
Year, per 1-yr increase	−0.38	−3.08	2.31	.78
Acetabuloplasty or femoroplasty§	8.21	2.05	14.38	<.001†
No osteoplasty§	38.14	19.81	56.47	
Labral debridement‖	27.60	13.04	42.16	<.001†
Simple labral repair‖	−3.35	−13.44	6.73	
BMAC or microfracture	−0.26	−0.32	−0.19	<.001†

NOTE. This model also included surgery center as a random intercept, with marginal $R^2 = 0.548$ and conditional $R^2 = 0.581$.
BMAC, bone marrow aspirate concentrate; CI, confidence interval; HOS-ADL, Hip Outcome Score−Activities of Daily Living.
**P* values calculated using likelihood-ratio tests.
†Statistically significant.
‡Reference category: Tönnis grade 0.
§Reference category: acetabular femoroplasty.
‖Reference category: labral repair with augmentation via capsular autograft.[43,44]

Table 6. Multivariable Mixed-Effects Model Evaluating Characteristics Underlying Variation in Value: Modified HOS-SS Analysis

Variable	Mean Difference	95% CI Lower	95% CI Upper	*P* Value*
Patient characteristics				
Age, per 1-yr increase	−0.16	−0.75	0.42	.47
Male sex	−5.82	−17.67	6.04	.43
Previous contralateral surgery	−16.57	−35.84	2.69	.080
Preoperative HOS-SS, per 1-point increase	0.39	0.16	0.61	<.001†
Preoperative or intraoperative findings				
Outerbridge grade	−5.12	−11.72	1.49	.14
Tönnis grade 1‡	−8.96	−19.72	1.80	.12
Case-specific factors				
Year, per 1-yr increase	0.97	−3.92	5.86	.85
Acetabuloplasty or femoroplasty§	8.31	−3.40	20.02	.022†
No osteoplasty§	52.03	17.65	86.41	
Labral debridement‖	29.07	1.31	56.84	.080
Simple labral repair‖	−3.90	−23.09	15.28	
BMAC or microfracture	−0.34	−0.46	−0.21	<.001†

NOTE. This model also included surgery center as a random intercept, with marginal $R^2 = 0.364$ and conditional $R^2 = 0.364$.
BMAC, bone marrow aspirate concentrate; CI, confidence interval; HOS-SS, Hip Outcome Score−Sports Subscale.
**P* values calculated using likelihood-ratio tests.
†Statistically significant.
‡Reference category: Tönnis grade 0.
§Reference category: acetabular femoroplasty.
‖Reference category: labral repair with augmentation via capsular autograft.[43,44]

Second, we deliberately compared patients in the 10th and 90th percentiles (rather than comparing the lowest- and highest-value patients) to reduce the impact of outliers in inflating measures of variation.[22,58] Thus, 20% of patients differ in value by more than 380%. Taken together, these 2 methodologic considerations strongly suggest that ample opportunity exists for reducing variation and optimizing value for patients.

Preoperative patient characteristics that significantly predicted value in the multivariable analysis included previous contralateral hip surgery, preoperative iHOT-33 score, and Tönnis grade. Our finding that previous contralateral hip surgery was associated with significantly lower value was unexpected and counterintuitive. On the basis of a recent hip arthroscopy TDABC analysis that revealed no differences in costs between patients with unilateral hip arthroscopy and those with bilateral hip arthroscopy,[12] we speculate that this result is most likely driven by inferior outcomes in the value equation. Previous literature is mixed on whether patients undergoing staged bilateral hip arthroscopy experience similar[59-62] or inferior[63] results to those undergoing unilateral hip arthroscopy; however, our results align with those of Kuhns et al.,[63] which suggest less improvement in the bilateral group. The positive association between value and preoperative iHOT-33 score likely also stemmed from the value side of the equation. Although preoperative PROMs have been correlated with postoperative outcomes in the context of rotator cuff repair and reverse total shoulder arthroplasty, similar studies in the field of hip arthroscopy remain scarce.[64,65] Our results indicate that patients with improved preoperative function may experience superior postoperative outcomes, which aligns with accumulating literature highlighting the importance of pursuing hip preservation surgery early in disease progression.[66,67] Consistent with this notion and previous literature associating higher Tönnis grades with inferior hip arthroscopy outcomes, our study revealed increased Tönnis grade to be associated with significantly lower value.[66,68-70] These findings may promote patient education and shared decision making, emphasizing the importance of narrow indications (e.g., functional patients with lower Tönnis scores) while guiding realistic expectations for patients with higher Tönnis grades.

In addition to these preoperative variables, 3 intraoperative factors significantly explained variation in value: osteoplasty type, method of labral management, and use of BMAC or microfracture. Specifically, more labor-intensive osteoplasty types (e.g., combined femoroacetabular decompression), labral management methods (e.g., repair), and treatment of cartilage defects (i.e., BMAC or microfracture) were associated with significantly lower value. A recent multicenter TDABC analysis of nearly 900 hip arthroscopy cases found each of these procedures to generate significantly higher costs; however, because this study did not integrate costs with outcomes, the impact of these procedures on patient value remained unclear.[12] Our study validates that these procedures are indeed costlier, and further suggests that they do not improve outcomes at a rate concordant with the increase in costs, as reflected by reduced value.

Given that each of these labor-intensive procedures is individually supported by a growing body of outcomes-based research, the aforementioned finding initially appears counterintuitive and warrants further discussion.[46,71-74] First, it illustrates why many insights derived from value-based analyses ought to be interpreted as descriptive, rather than prescriptive. Identifying that Tönnis grade 1 is associated with lower value than Tönnis grade 0 does not imply that the former patients who are otherwise appropriate surgical candidates should be urged against surgery, only that they may, on average, achieve lower value. Second, and relatedly, these results should not be used to justify treating statistics, rather than patients, and clinical care should continue to be guided by patient education and shared decision making. Although it may be true that, all else being equal, a patient requiring combined femoroacetabular decompression may achieve lower value than a patient receiving isolated acetabuloplasty, it is also true that the former patient would achieve much lower value if he or she was mistakenly treated with only acetabuloplasty; the 2 patients present with distinct conditions and should be treated as such. Finally, this finding highlights that not all "value" information is equivalent, and all conclusions should be carefully interpreted based on study methodology. In the context of our study, value was calculated using 2-year outcomes, and it is plausible, if not likely, that longer follow-up is required to truly appreciate the value improvements conferred by more labor-intensive procedures, such as labral repair or BMAC augmentation.[46,71-74]

Finally, value drivers were identified between different PROMs (i.e., iHOT-33 score, HOS-ADL, and HOS-SS), reflecting the multidimensional nature of patient outcomes. Some variables—such as preoperative PROM scores, osteoplasty type, and use of BMAC or microfracture—consistently explained value across all 3 adjusted analyses. We therefore speculate that these factors are very likely to influence value in multiple domains that matter to patients, ranging from activities of daily living to athletic endeavors. Other variables, such as Outerbridge grade, Tönnis grade, and labral management technique, were found to be significant value drivers in some, but not all, multivariable models. For example, higher Outerbridge grade was associated with lower value in only the HOS-ADL model, whereas Tönnis grade and labral management technique predicted value in all models except the HOS-SS model. These variations are reasonable given that these instruments are designed to measure different outcomes.[75,76] However, this finding highlights the importance of reporting a variety of value-based measures that capture distinct patient outcomes because no single outcome fully captures a patient's experience with care.[6]

Limitations

The conclusions of this study should be interpreted in the context of certain limitations. First, all surgical procedures were performed by a single high-volume orthopaedic surgeon at an urban orthopaedic specialty hospital in the northeastern United States, which may reduce the generalizability of the study findings. Second, our single-surgeon design precluded investigation of intersurgeon variation in value, which may arise from differences in technical skill, case volume, and surgical technique. Third, although TDABC costs measured the preoperative, intraoperative, and postoperative phases of each outpatient visit, we did not capture pre— or post—acute care costs, which may include clinic visits, postoperative rehabilitation, and rarely, rehospitalization. Of note, previous investigations performed by the senior surgeon (S.D.M.) have revealed low complication rates (i.e., $<2\%$ requiring readmission) for similar patient samples[38,77]; thus, our analysis likely captures most total episode-of-care costs. Relatedly, although the development of TDABC process maps was informed by direct observation and multiple staff interviews, the process inherently involves subjective judgment and may introduce bias. Finally, and perhaps most important, the 2-year follow-up period may be insufficient to capture certain value improvements (e.g., reduced rates of conversion to total hip arthroplasty), particularly those associated with labor-intensive procedures such as labral repair or BMAC augmentation.[46,71-74]

Conclusions

This study revealed wide variation in the value of hip arthroscopy that was most strongly explained by osteoplasty type, labral management technique, and preoperative PROMs. In contrast, patient demographic characteristics such as age, sex, and BMI contributed minimal independent variability.

Disclosures

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: A.P.B.d.S.E. reports a consulting or advisory relationship with Avant-garde Health. S.D.M. reports that support was provided by the Conine Family Fund for Joint Preservation. All other authors (M.C.D., N.J.C., Z.L.L., K.S.D., K.A.T., R.E.D.) declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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