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Evaluating Patient and Surgeon Characteristics Associated with Care Cost and Outcomes for Knee and Hip Replacement Procedures

A National Medicare Cohort Study

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Background: The role of physician credentialing has been widely considered in quality and outcome improvement studies. However, the association between surgeon characteristics and health-care costs remains unclear.

Methods: Our objective was to determine the association of orthopaedic surgeon characteristics with health outcomes and costs, utilizing Medicare data. We used 100% Fee-for-Service Medicare data from 2015 to 2019 to identify all patients ≥65 years of age who underwent 2 common orthopaedic surgical procedures, total hip and knee replacement. After determining whether the patients had been readmitted after discharge from their initial admission for surgery, we computed 3 metrics of total medical expenditure: the costs of the initial surgery admission and 30-day and 180-day episode-based bundles of care. Hierarchical linear regression and logistic regression models were used to evaluate patient and surgeon characteristics associated with care costs and the likelihood of readmission.

Results: We identified 2,269 surgeons who performed total knee replacements on 298,934 patients and 1,426 surgeons who performed total hip replacements on 204,721 patients. Patient characteristics associated with higher initial surgery costs included increasing age, female sex, racial minority status, and a higher Charlson Comorbidity Index. Surgeon characteristics associated with lower readmission rates included practice in the Northeast region and a higher patient volume; having malpractice claims was associated with higher readmission rates.

Conclusions: A higher volume of patients treated by the orthopaedic surgeon was associated with lower overall costs and readmission rates. Information on surgeons' malpractice claims and annual volume should be made publicly available to assist patients, payer networks, and hospitals in surgeon selection and oversight. These results could also inform the guidelines of physician credentialing organizations.

Level of Evidence: Prognostic Level III. See Instructions for Authors for a complete description of levels of evidence.

Total knee and hip replacement are 2 of the most commonly performed orthopaedic surgery procedures in the United States[1]. Previous studies have shown that certain patient characteristics such as older age, female sex, Black race, Hispanic ethnicity, and comorbidities are associated with poor postoperative outcomes[2,3].

The role of physician credentialing has been widely studied as a factor in outcome and quality improvement studies in several specialties[4-7]. Board certification allows physicians to demonstrate achievements beyond the minimum standards for licensure. Most hospitals in the United States require board certification for credentialing of clinical staff[8]. Previous research has shown that institutions that require additional specialty education, including a dedicated subspecialty fellowship, can reduce postoperative complications, significantly reducing morbidity and mortality, in surgical populations[6]. One study concluded that patients undergoing a knee replacement by a fellowship-trained surgeon achieved a higher activity measure than those treated by a surgeon without fellowship training[9]. Another study found an association between neurosurgical fellowship training and

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improved patient safety and outcomes[4]. In addition, researchers found an association between board certification and outcomes after myocardial infarction in elderly patients[5]. However, the association between surgeon characteristics and health-care costs in orthopaedic surgery is still unclear.

Our aim was to promote high-value care by conducting a high-powered study to evaluate and identify patient and surgeon characteristics, such as fellowship training, board certification, and malpractice status, associated with inpatient surgery costs and with readmission following discharge after the initial surgery.

Materials and Methods

Data Source

We used 100% Fee-for-Service Medicare data to identify all patients ≥65 years of age who underwent 2 key surgical procedures, total knee replacement (TKR) and total hip replacement (THR), between January 1, 2015, and December 31, 2019. The Council for Affordable Quality Healthcare (CAQH) database was used to identify surgeons' credentialing and training background. CAQH is an online database of credentialing information that includes information on practitioners' self-reported demographics, education and training, work history, malpractice history, and other relevant credentialing information. The Johns Hopkins University institutional review board approved this study. Informed consent was waived because the data do not incorporate patient identifiable information.

Outcomes

The primary outcome for this study was total medical expenditure for the initial surgery admission and 30-day and 180-day episode-based bundles of care. Based on a prior study, episode-based spending was identified as all Fee-for-Service Medicare claims originating from an initial admission for a procedure[10]. The secondary outcome was whether patients were readmitted to a hospital within 30 and 180 days after discharge.

We identified total spending on the basis of the components of care, including spending on the index hospitalization and readmission using inpatient claims, and spending on post-acute care using skilled nursing facility claims and home health agency claims, physician carrier claims, and outpatient claims[11,12]. We did not include prescription pharmacy costs in the evaluation. For inpatient claims, the Medicare claim payment amount does not include the claim pass-through per diem payments made by Medicare. Thus, to obtain the total amount paid by Medicare, we used the Medicare claims payment amount plus the pass-through per diem payment multiplied by the number of Medicare-covered days. For skilled nursing facility, home health agency, hospice, hospital outpatient center, and other non-institutional services (physician carrier claims), the claim payment amount is the total amount actually paid by Medicare[13]. Finally, to obtain the total cost, we calculated the sum of the amounts paid by Medicare, the primary payer if that was not Medicare, and the beneficiary, and charges not covered by insurance.

For each patient, the total medical spending and spending for each component were also calculated for the 30- and 180-day periods starting with the initial surgery. All costs were attributed to the physician who performed the initial surgical procedure, regardless of the physician who performed subsequent care or its location.

Independent Variables

Patient Characteristics

We extracted patient demographic details, including age, gender, race and ethnicity, and residential ZIP code, from the Medicare Master Beneficiary Summary File. Race was classified as White, Black, Hispanic, Asian, North American Native, and Other or Unknown. We categorized age groups as 65 to 69, 70 to 74, 75 to 79, 80 to 84, and ≥85 years. ZIP codes were mapped to Federal Information Processing Standard (FIPS) codes using the sashelp.zipcode file (SAS Institute). FIPS codes were then linked to core-based statistical area (CBSA) codes using a CBSA to FIPS County Crosswalk provided by the National Bureau of Economic Research[14]. CBSA codes were employed to ascertain whether the patient's residential location fell within a metropolitan area (urban core with a population of ≥50,000) or a rural area (i.e., a non-metropolitan region). We examined the inpatient, outpatient, and carrier claims of every patient in the 12 months leading up to the date of the index surgical procedure to assess their Charlson Comorbidity Index, in accordance with the methodology outlined in prior studies[15,16].

Surgeon Characteristics

The National Provider Identifier (NPI) for each claim was used to identify the surgeon who performed the index surgical procedure. We obtained surgeon characteristics from the Medicare Data on Provider Practice and Specialty (MD-PPAS) and the Physician Compare National Downloadable File[17,18]. Surgeon characteristics included sex, years since graduation from medical school, region, and population density status (metropolitan versus rural) of their practice location. We included only surgeons who performed an average of ≥11 procedures annually during the study period, in accordance with our Medicare data use agreement, to protect patients' privacy.

Credentialing Criteria

We used CAQH data to identify surgeons' credentialing and training background. After identifying the surgeon cohorts for each of the 2 index surgical procedures, the data were linked to the external surgeon credentialing and training data using their NPI. We identified 3 credentialing criteria, including fellowship training, board certification, and state licensing. We also included surgeons' malpractice history as a binary variable.

Surgical Inpatient Procedures

We identified the 2 surgical procedures of interest using procedure-specific Current Procedural Terminology (CPT) and Diagnosis Related Group (DRG) codes: CPT 27447 and DRG 470 for knee replacement, and CPT 27130 and DRG 470 for hip replacement. We only included procedures performed in a hospital inpatient setting with valid DRG codes corresponding to the procedure of interest[19]. The provider specialty code in the carrier line claims had to be 20, indicating orthopaedic surgery[20]. The admission and

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TABLE I Medicare Fee-for-Service Patient Characteristics for 2 Common Orthopaedic Procedures in the United States

	Knee Replacement (N = 298,934)	Hip Replacement (N = 204,721)
Age		
Mean ± SD *(yr)*	74.19 ± 5.71	74.61 ± 6.17
Median (IQR) *(yr)*	73.31 (69.51 to 78.01)	73.53 (69.57 to 78.70)
65-74 yr	178,849 (59.83%)	118,620 (57.94%)
75-84 yr	105,878 (35.42%)	71,760 (35.05%)
≥85 yr	14,207 (4.75%)	14,341 (7.01%)
Sex		
Female	189,874 (63.52%)	124,918 (61.02%)
Male	109,060(36.48%)	79,803 (38.98%)
Race and ethnicity		
Asian	1,835 (0.61%)	425 (0.21%)
Black	12,163 (4.07%)	6,971 (3.41%)
Hispanic	1,900 (0.64%)	466 (0.23%)
North American Native	1,115 (0.37%)	476 (0.23%)
White	274,782 (91.92%)	191,113 (93.35%)
Other or unknown	7,139 (2.39%)	5,270 (2.57%)
Surgery year		
2015	57,191 (19.13%)	33,488 (16.36%)
2016	64,048 (21.43%)	37,089 (18.12%)
2017	67,970 (22.74%)	40,401 (19.73%)
2018	54,428 (18.21%)	44,442 (21.71%)
2019	55,297 (18.50%)	49,301 (24.08%)
Total Charlson Comorbidity Index		
Mean ± SD	1.16 ± 1.64	1.12 ± 1.66
Median (IQR)	1.00 (0 to 2)	0 (0 to 2)
0	145,336 (48.62%)	105,560 (51.56%)
1-2	104,395 (34.92%)	67,582 (33.01%)
3-4	34,039 (11.39%)	21,506 (10.51%)
5-6	10,700 (3.58%)	6,545 (3.20%)
≥7	4,464 (1.49%)	3,528 (1.72%)
Region		
Midwest	77,988 (26.09%)	52,418 (25.60%)
Northeast	56,623 (18.94%)	43,538 (21.27%)
South	121,605 (40.68%)	74,275 (36.28%)
West	42,638 (14.26%)	34,438 (16.82%)
Other	80 (0.03%)	52 (0.03%)

discharge dates were determined from the inpatient claims, and the procedure date was determined from the carrier line claims. Patients who underwent bilateral procedures were excluded. We only included patients who underwent 2 or more hip or knee replacements if these procedures had been done at least 180 days apart, to avoid biasing the outcomes.

Statistical Analysis

Patient and surgeon characteristics for each procedure were summarized as the mean and standard deviation (SD) or the median and interquartile range (IQR), as appropriate. A hierarchical linear regression model was used to evaluate patient and surgeon characteristics associated with the cost of care. Only the middle 95% of the sample was used in the modeling, to avoid extremely low or high-cost outliers. Assessment of the impact of credentialing on the cost of postoperative care was performed by performing univariate analyses of the impact of patient and surgeon characteristics followed by multivariable analyses involving all of the characteristics. The model used a surgeon-level random intercept to account for clustering of patients treated by the same surgeon. Similar logistic regression models were used to identify factors associated with patient readmission within 30 and 180 days after the inpatient procedure. All statistical analyses were performed using SAS Enterprise (version 7.1; SAS Institute).

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TABLE II Surgeon Characteristics

	Knee Replacement (N = 2,269)	Hip Replacement (N = 1,426)
Physician sex		
Female	26 (1.15%)	10 (0.70%)
Male	2,243 (98.85%)	1,416 (99.30%)
Annual no. of patients		
Mean ± SD	27.14 ± 20.02	26.75 ± 17.82
Median (IQR)	20 (14.4 to 31.8)	20.8 (14.40 to 32.40)
Time since graduating from medical school		
Mean ± SD *(yr)*	24.24 ± 8.89	22.69 ± 9.41
Median (IQR) *(yr)*	24 (17 to 31)	22 (15 to 30)
0-10 yr	132 (5.82%)	153 (10.73%)
11-20 yr	670 (29.53%)	470 (32.96%)
21-30 yr	849 (37.42%)	455 (31.91%)
≥31 yr	589 (25.96%)	328 (23.00%)
Unknown	29 (1.28%)	20 (1.40%)
Region		
Midwest	650 (28.65%)	399 (27.98%)
Northeast	384 (16.92%)	282 (19.78%)
South	907 (39.97%)	513 (35.97%)
West	326 (14.37%)	232 (16.27%)
Other	2 (0.09%)	0 (0.00%)
Urban		
Rural	298 (13.13%)	135 (9.47%)
Urban	1,971 (86.87%)	1,291 (90.53%)
Fellowship training		
No	890 (39.22%)	429 (30.08%)
Yes	1,379 (60.78%)	997 (69.92%)
Board certification		
No	344 (15.16%)	195 (13.67%)
Yes	1,925 (84.84%)	1,231 (86.33%)
State license		
No	31 (1.37%)	23 (1.61%)
Yes	2,238 (98.63%)	1,403 (98.39%)
Malpractice claim		
No	1,394 (61.44%)	910 (63.81%)
Yes	875 (38.56%)	516 (36.19%)

Results

Patient Characteristics

We identified 298,934 patients who underwent knee replacement and 204,721 patients who underwent hip replacement during the study period (Table I). The mean patient age was 74.2 ± 5.7 years for knee replacement and 74.6 ± 6.2 years for hip replacement. Patients treated with each procedure were predominantly female and White (63.5% [189,874] female and 274,782 [91.9%] White for knee replacement, and 61.0% [124,918] female and 93.4% [191,113] White for hip replacement). The greatest proportion of patients resided in the Southern region (TKR: 121,605 [40.7%]; THR: 74,275 [36.3%]).

Surgeon Characteristics

We identified 2,269 surgeons who performed the knee replacements and 1,426 surgeons who performed the hip replacements (Table II). The 2 surgeon cohorts were similar with respect to predominantly being male, practicing in the South and Midwest and in a metropolitan location, and having board certification and state licensing. Only 60.8% of surgeons from the knee replacement cohort and 69.9% of surgeons from the hip

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TABLE III Adjusted Model of Patient and Surgeon Characteristics Associated with Knee Replacement Costs*

	Adjusted Difference Between Average Costs (95% CI) *($)*		
	Index Knee Replace Surgery	Index Knee Replace Surgery and within 30 Days of Index Admission	Index Knee Replace Surgery and within 180 Days of Index Admission
Patient characteristics			
Age			
65-74 yr	Ref.	Ref.	Ref.
75-84 yr	993.47 (963.07 to 1,023.86)	1,230.12 (1,195.59 to 1,264.65)	1,297.04 (1,246.61 to 1,347.46)
≥85 yr	3,262.28 (3,194.24 to 3,330.32)	4,056.96 (3,979.72 to 4,134.19)	4,414.83 (4,302.24 to 4,527.42)
Sex			
Female	864.13 (834.39 to 893.86)	994.86 (961.09 to 1,028.63)	1,053.82 (1,004.47 to 1,103.16)
Male	Ref.	Ref.	Ref.
Race and ethnicity			
Asian	700.66 (514.05 to 887.28)	826.20 (615.15 to 1,037.25)	842.53 (537.96 to 1,147.10)
Black	1,037.21 (961.55 to 1,112.87)	1,233.09 (1,147.36 to 1,318.83)	1,122.77 (998.06 to 1,247.49)
Hispanic	205.72 (20.17 to 391.27)	425.68 (216.24 to 635.13)	182.38 (−122.13 to 486.86)
North American Native	181.92 (−58.06 to 432.91)	86.67 (−185.66 to 359.01)	−245.26 (−642.67 to 152.15)
White	Ref.	Ref.	Ref.
Other or unknown	139.11 (45.43 to 232.79)	187.74 (81.55 to 293.93)	103.00 (−51.66 to 257.66)
Surgery year			
2015	Ref.	Ref.	Ref.
2016	−754.95 (−800.08 to −709.83)	−807.26 (−858.31 to −756.21)	−755.53 (−850.08 to −700.99)
2017	−1,160.00 (−1,205.68 to −1,114.31)	−1,260.64 (−1,312.45 to −1,208.84)	−1,138.93 (−1,214.36 to −1,063.49)
2018	−1,362.55 (−1,412.47 to −1,312.63)	−1,458.82 (−1,515.56 to −1,402.08)	−1,176.58 (−1,258.85 to −1,094.30)
2019	−1,647.54 (−1,699.45 to −1,595.63)	−1,761.76 (−1,820.89 to −1,702.64)	−1,381.27 (−1,466.69 to −1,295.84)
Total Charlson Comorbidity Index			
0	Ref.	Ref.	Ref.
1-2	524.8 (493.16 to 556.45)	710.26 (674.40 to 746.22)	1,314.65 (1,262.21 to 1,367.10)
3-4	1,115.69 (1,068.48 to 1,162.90)	1,522.49 (1,468.82 to 1,576.16)	2,634.92 (2,556.48 to 2,713.36)
5-6	1,672.71 (1,594.30 to 1,751.12)	2,313.52 (2,224.18 to 2,402.86)	3,657.97 (3,527.06 to 3,788.87)
≥7	1,993.40 (1,874.68 to 2,112.12)	2,820.25 (2,684.21 to 2,956.29)	5,575.06 (5,373.81 to 5,776.32)
Readmission			
No		Ref.	Ref.
Yes		9,972.52 (9,880.42 to 10,065)	15,819 (15,735 to 15,903)
Surgeon characteristics			
Physician sex			
Female	589.64 (−283.91 to 1,463.19)	150.40 (−911.57 to 1,212.37)	−299.20 (−1,524.53 to 926.13)
Male	Ref.	Ref.	Ref.
Time since graduating from medical school			
0-10 yr	−284.45 (−463.20 to −105.70)	−261.68 (−466.92 to −56.45)	−407.17 (−691.59 to −122.75)
11-20 yr	−40.19 (−160.59 to 80.21)	12.01 (−126.60 to 150.62)	−5.61 (−196.32 to 185.11)
21-30 yr	9.92 (–77.05 to 96.89)	35.35 (−64.24 to 134.93)	−18.61 (−158.32 to 121.09)
≥31 yr	Ref.	Ref.	Ref.
Unknown	−197.41 (−1,020.91 to 626.10)	22.82 (−980.95 to 1,026.60)	157.16 (−1,000.26 to 1,314.59)

continued

TABLE III (*continued*)

	Adjusted Difference Between Average Costs (95% CI) *($)*		
	Index Knee Replace Surgery	Index Knee Replace Surgery and within 30 Days of Index Admission	Index Knee Replace Surgery and within 180 Days of Index Admission
Region			
Midwest	398.05 (169.25 to 626.85)	140.53 (−138.43 to 419.49)	−143.09 (−464.31 to 178.13)
Northeast	2,999.95 (2,729.97 to 3,269.94)	3,493.10 (3,164.13 to 3,822.07)	3,812.65 (3,434.12 to 4,191.19)
South	Ref.	Ref.	Ref.
West	1,721.43 (1,436.45 to 2,006.41)	1,556.65 (1,209.14 to 1,904.17)	1,854.29 (1,454.27 to 2,254.32)
Other	932.52 (−2,170.38 to 4,035.42)	1,569.43 (−2,215.74 to 5,354.60)	1,844.08 (−2,516.97 to 6,205.12)
Urban			
Rural	269.67 (−11.05 to 550.38)	33.25 (−308.38 to 374.87)	−147.31 (−540.91 to 246.29)
Urban	Ref.	Ref.	Ref.
Annual patient volume†			
1st quartile	Ref.	Ref.	Ref.
2nd quartile	−297.03 (−520.20 to −73.86)	−395.90 (−667.96 to −123.85)	−454.39 (−767.71 to −141.06)
3rd quartile	−441.77 (−705.61 to −177.93)	−546.07 (−867.94 to −224.21)	−591.37 (−961.16 to −221.58)
4th quartile	−738.66 (−1,064.84 to −412.48)	−946.30 (−1,344.47 to −548.14)	−986.23 (−1,442.68 to −529.79)
Fellowship training			
No	−96.86 (−292.99 to 99.27)	−211.64 (−450.56 to 27.28)	−352.33 (−628.09 to −76.58)
Yes	Ref.	Ref.	Ref.
Board certification			
No	−46.85 (−303.89 to 210.19)	−124.34 (−437.69 to 189.01)	−171.78 (−532.48 to 188.92)
Yes	Ref.	Ref.	Ref.
State license		−311.03 (−1,278.73 to 656.67)	
No	−118.94 (−913.53 to 675.65)		−247.29 (−1,361.50 to 866.93)
Yes	Ref.	Ref.	Ref.
Malpractice claim			
No	Ref.	Ref.	Ref.
Yes	151.85 (−39.46 to 343.17)	209.57 (−23.62 to 442.76)	298.68 (30.02 to 567.33)
outdent per Word document	16,060 (15,792 to 16,267)	18,668 (18,382 to 18,955)	20,970 (20,628 to 21,312)

*Surgeons with <11 procedures per year were not included in this study, per the Medicare data use agreement. †Knee replacement surgeon annual volume: quartile 1, 11 to 18.9 patients; quartile 2, 19 to 30.7 patients; quartile 3, 30.8 to 50.9 patients; quartile 4, ≥51 patients.

replacement cohort had fellowship training, and 38.6% (875) of knee replacement surgeons and 36.2% (516) of hip replacement surgeons had at least 1 malpractice claim during the study period.

Patient and Surgeon Characteristics Associated with Costs

Knee Replacement

The following factors were significantly associated with increases in the cost of the index knee replacement, after adjusting for patient and surgeon characteristics: greater patient age (by $993.47 [95% confidence interval (CI): $963.07 to $1,023.86] for 75 to 84-year-olds and $3,262.28 [95% CI: $3,194.24 to $3,330.32] for ≥85-year-olds compared with the 65 to 74-year age group), female sex ($864.13 [95% CI: $834.39 to $893.86]), Black race ($1,037.21 [95% CI: $961.55 to $1,112.87]), and a higher Charlson Comorbidity Index (ranging from $524.80 to $1,993.40). The following factors were significantly associated with decreases in the cost: surgeons who had recently started a medical career (−$284.45 [95% CI: −$463.20 to −$105.70] for ≤10 years since graduation from medical school compared with ≥31 years of practice) and who had higher patient volume (ranging from −$297.03 to −$738.66 for the 2nd to 4th quartiles compared with the 1st quartile). The greatest decrease in costs was observed for surgeons with an annual patient volume of ≥51. Costs were higher for surgeons practicing in the Northeast ($2,999.95 [95% CI: $2,729.97 to $3,269.94]), West ($1,721.43 [95% CI: $1,436.45 to $2,006.41]), and Midwest ($398.05 [95% CI: $169.25 to $626.85]) compared with the South (Table III).

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TABLE IV Adjusted Model of Patient and Surgeon Characteristics Associated with Hip Replacement Costs*

	Adjusted Difference Between Average Costs (95% CI) ($)		
	Index Hip Replacement Surgery	Index Hip Replacement Surgery and within 30 Days of Index Admission	Index Hip Replacement Surgery and within 180 Days of Index Admission (95% CI)
Patient characteristics			
Age			
65-74 yr	Ref.	Ref.	Ref.
75-84 yr	1,083.24 (1,041.98 to 1,124.51)	1,478.83 (1,427.91 to 1,529.75)	1,673.55 (1,598.19 to 1,748.92)
≥85 yr	3,922.5 (3,845.66 to 3,999.34)	5,196.23 (5,101.64 to 5,290.83)	5,862.94 (5,723.20 to 6,002.68)
Sex			
Female	891.37 (852.13 to 930.60)	1,220.23 (1,171.85 to 1,268.61)	1,430.24 (1,358.57 to 1,501.92)
Male	Ref.	Ref.	Ref.
Race and ethnicity			
Asian	441.19 (36.57 to 845.81)	960.56 (466.96 to 1,454.21)	1,108.11 (384.00 to 1,832.21)
Black	890.21 (778.71 to 1,001.71)	1,043.17 (906.43 to 1,179.92)	757.11 (554.93 to 959.30)
Hispanic	950.58 (536.72 to 1,364.43)	1,178.51 (672.24 to 1,684.78)	1082.17 (335.94 to 1,828.39)
North American Native	504.98 (90.71 to 919.26)	562.38 (50.80 to 1,073.97)	148.65 (−614.24 to 911.53)
White	Ref.	Ref.	Ref.
Other or unknown	−20.46 (−138.98 to 98.07)	−67.21 (−213.41, 78.98)	−197.90 (−414.62, 18.83)
Surgery year			
2015	Ref.	Ref.	Ref.
2016	−785.87 (−851.71 to −720.04)	−883.34 (−963.82, −802.86)	−905.03 (−1,023.87 to −786.20)
2017	−1,185.85 (−1,251.61 to −1,120.10)	−1,336.87 (−1,417.60 to −1,256.15)	−1,312.28 (−1.431.22 to −1,193.34)
2018	−1,332.45 (−1,398.65 to −1,266.26)	−1,569.64 (−1,651.13 to −1,488.16)	−1,404.95 (−1,524.59 to −1,285.31)
2019	−1,444.1 (−1,511.47 to −1,376.73)	−1,814.08 (−1,897.05 to −1,731.11)	−1,664.3 (−1785.55 to −1543.05)
Total Charlson Comorbidity Index			
0	Ref.	Ref.	Ref.
1-2	552.3 (509.62 to 594.98)	849.47 (796.84 to 902.10)	1,561.54 (1,483.64 to 1639.44)
3-4	1,252.44 (1,187.16 to 1,317.73)	1,825.97 (1,745.33 to 1,906.62)	3,201.43 (3,081.94 to 3,320.91)
5-6	2,044.33 (1,933.10 to 2,155.55)	2,906.21 (2,769.24 to 3,043.18)	4,534.74 (4,330.79 to 4,738.70)
≥7	2,172.62 (2,024.53 to 2,320.70)	3,508.67 (3,325.06 to 3,692.27)	6,772.17 (6,495.24 to 7,049.09)
Readmission			
No		Ref.	Ref.
Yes		12,774 (12,637 to 12,911)	19,970 (19,850 to 20,091)
Surgeon characteristics			
Physician sex			
Female	49.79 (−1,317.42 to 1,417.01)	−549.52 (−2,283.13 to 1184.10)	−947.22 (−2,945.61 to 1,051.16)
Male	Ref.	Ref.	Ref.
Time since graduating from medical school			
0-10 yr	61.23 (−156.28 to 278.73)	−27.56 (−296.95 to 241.82)	−181.98 (−553.22 to 189.26)
11-20 yr	−84.96 (−246.85 to 76.92)	−209.08 (−409.74 to −8.41)	−387 (−662.32 to −111.69)
21-30 yr	4.98 (−116.32 to 126.27)	−91.2 (−241.26 to 58.86)	−186.91 (−398.58 to 24.76)
≥31 yr	Ref.	Ref.	Ref.
Unknown	−63.56 (−1,036.01 to 908.88)	51.97 (−1,180.86 to 1,284.80)	79.03 (−1,345.22 to 1,503.27)
Region			
Midwest	392.21 (98.75 to 685.66)	−119.68 (−491.82 to 252.47)	−299.66 (−729.01 to 129.69)
Northeast	3,058.73 (2,734.01 to 3,383.45)	3,599.44 (3,187.64 to 4,011.23)	3,914.31 (3,439.84 to 4,388.79)

continued

TABLE IV (*continued*)

	Adjusted Difference Between Average Costs (95% CI) *($)*		
	Index Hip Replacement Surgery	Index Hip Replacement Surgery and within 30 Days of Index Admission	Index Hip Replacement Surgery and within 180 Days of Index Admission (95% CI)
South	Ref.	Ref.	Ref.
West	1,684.37 (1,342.25 to 2,026.48)	1,267.5 (833.67 to 1,701.43)	1,420.80 (920.79 to 1,920.81)
Urban			
Rural	433.57 (32.10 to 835.05)	433.11 (−75.91 to 942.13)	141.12 (−446.61 to 728.84)
Urban	Ref.	Ref.	Ref.
Annual patient volume†			
1st quartile	Ref.	Ref.	Ref.
2nd quartile	−605.84 (−882.60 to −329.07)	−747.49 (−1,098.45 to −396.54)	−825.99 (−1,231.05 to −420.92)
3rd quartile	−788.19 (−1,112.38 to −464.00)	−1,170.25 (−1,581.45 to −759.06)	−1,177.46 (−1,650.60 to −704.32)
4th quartile	−1,055.61 (−1,460.89 to −650.33)	−1,368.28 (−1,882.45 to −854.12)	−1,400.53 (−1,990.49 to −810.58)
Fellowship training			
No	−121.06 (−380.58 to 138.47)	−327.5 (−656.43 to 1.44)	−536.07 (−917.00 to −155.13)
Yes	Ref.	Ref.	Ref.
Board certification			
No	−84.00 (−416.33 to 248.33)	−13.54 (−435.17 to 408.09)	−181.46 (−667.55, 304.63)
Yes	Ref.	Ref.	Ref.
State license			
No	49.19 (−855.17 to 953.55)	−56.89 (−1,203.64 to 1,089.86)	151.56 (−1,169.47 to 1,472.58)
Yes	Ref.	Ref.	Ref.
Malpractice claim			
No	Ref.	Ref.	Ref.
Yes	203.22 (−39.30 to 445.74)	243.47 (−63.89 to 550.84)	341.11 (−14.21 to 696.43)
Intercept	16,189 (15,888 to 16,490)	18,716 (18,336 to 19,096)	20,638 (20,178 to 21,098)

*Surgeons with <11 procedures per year were not included in this study, per the Medicare data use agreement. †Hip replacement surgeon annual volume: quartile 1, 11 to 18.9 patients; quartile 2, 19 to 30.3 patients; quartile 3, 30.4 to 49.1 patients; quartile 4, ≥49.2 patients.

Patient characteristics significantly associated with the 30 and 180-day episode-based bundle-of-care costs were similar to those for the index surgery. Patients who were readmitted to the hospital during the 30 or 180-day window incurred significantly higher costs than those who were not (by $9,972 [95% CI: $9,880 to $10,065] for 30 days and $15,819 [95% CI: $15,735 to $15,903] for 180 days). Surgeons with fewer years since graduation from medical school and those who had higher patient volumes were again associated with lower overall costs (Table III).

Hip Replacement

The following factors were significantly associated with increases in the cost of the index hip replacement, after adjusting for patient and surgeon characteristics: greater patient age (by $1,083.24 [95% CI: $1,041.98 to $1,124.51] for 75 to 84-year-olds and $3,922.50 [95% CI: $3,845.66 to $3,999.34] for ≥85-year-olds compared with the 65 to 74-year age group), female sex ($891.37 [95% CI: $852.13 to $930.60]), Hispanic ethnicity ($950.58 [95% CI: $536.72 to $1,364.43]), Black race ($890.21 [95% CI: $778.71 to $1,001.71]), and higher Charlson Comorbidity Index (ranging from $552.30 to $2,172.62). The following factor was significantly associated with decreases in the cost: surgeons with a higher patient volume (ranging from −$605.84 to −$1,055.61 for the 2nd to 4th quartiles compared with the 1st quartile). The greatest decrease in costs was observed in surgeons with an annual patient volume of >49. Costs were higher for surgeons practicing in the Northeast ($3,058.73 [95% CI: $2,734.01 to $3,383.45]), West ($1,684.37 [95% CI: $1,342.25 to $2,026.48]), and Midwest ($392.21 [95% CI: $98.75 to $685.66]) compared with the South (Table IV).

Patient characteristics associated with the 30 and 180-day episode-based bundle-of-care costs were similar to those for the index surgery. Patients who were readmitted to hospital during the 30 or 180-day window incurred significantly higher costs than those who were not (by $12,774 [95% CI: $12,637 to $12,911] for 30 days and $19,970 [95% CI: $19,850 to $20,091] for 180 days). Surgeons who had higher patient volumes were again associated with lower overall costs (Table IV).

Patient and Surgeon Characteristics Associated with Readmission

Knee Replacement

In the multivariable logistic model adjusted for patient and surgeon characteristics, the following factors were associated

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TABLE V Logistic Regression Model of Patient and Surgeon Characteristics Associated with Hospital Readmission*

	Odds Ratio (95% CI) for Readmission to Hospital			
	Within 30 Days After Knee Replacement	Within 180 Days After Knee Replacement	Within 30 Days After Hip Replacement	Within 180 Days After Hip Replacement
Patient characteristics				
Age				
65-74 yr	Ref.	Ref.	Ref.	Ref.
75-84 yr	1.509 (1.445 to 1.577)	1.309 (1.274 to 1.346)	1.335 (1.259 to 1.415)	1.200 (1.159 to 1.243)
≥85 yr	1.938 (1.785 to 2.104)	1.744 (1.654 to 1.840)	1.949 (1.783 to 2.131)	1.709 (1.616 to 1.807)
Sex				
Female	0.784 (0.751 to 0.818)	0.853 (0.830 to 0.876)	0.946 (0.895 to 1.000)	0.953 (0.922 to 0.985)
Male	Ref.	Ref.	Ref.	Ref.
Race and ethnicity				
Asian	0.746 (0.547 to 1.017)	0.766 (0.637 to 0.921)	0.498 (0.221 to 1.124)	0.840 (0.583 to 1.210)
Black	1.004 (0.904 to 1.114)	0.953 (0.891 to 1.018)	0.865 (0.741 to 1.010)	0.865 (0.789 to 0.949)
Hispanic	0.946 (0.723 to 1.237)	0.940 (0.795 to 1.112)	1.160 (0.687 to 1.959)	0.775 (0.534 to 1.124)
North American Native	1.261 (0.933 to 1.704)	1.063 (0.867 to 1.304)	1.145 (0.671 to 1.955)	1.000 (0.709 to 1.410)
White	Ref.	Ref.	Ref.	Ref.
Other or unknown	0.830 (0.708 to 0.972)	0.804 (0.729 to 0.886)	0.807 (0.658 to 0.991)	0.861 (0.768 to 0.964)
Surgery year				
2015	Ref.	Ref.	Ref.	Ref.
2016	0.944 (0.885 to 1.007)	0.978 (0.939 to 1.019)	1.018 (0.931 to 1.113)	0.991 (0.939 to 1.045)
2017	0.966 (0.907 to 1.029)	0.932 (0.895 to 0.970)	0.961 (0.879 to 1.020)	0.941 (0.892 to 0.992)
2018	0.925 (0.864 to 0.989)	0.912 (0.873 to 0.952)	0.882 (0.807 to 0.964)	0.881 (0.835 to 0.929)
2019	0.848 (0.791 to 0.909)	0.976 (0.935 to 1.018)	0.865 (0.792 to 0.944)	0.911 (0.865 to 0.960)
Total Charlson Comorbidity Index				
0	Ref.	Ref.	Ref.	Ref.
1-2	1.397 (1.331 to 1.466)	1.399 (1.358 to 1.442)	1.374 (1.291 to 1.463)	1.430 (1.378 to 1.484)
3-4	1.717 (1.612 to 1.829)	1.795 (1.725 to 1.867)	1.829 (1.685 to 1.987)	1.920 (1.827 to 2.018)
5-6	2.248 (2.054 to 2.461)	2.264 (2.134 to 2.402)	2.197 (1.941 to 2.486)	2.462 (2.282 to 2.655)
≥7	2.398 (2.104 to 2.734)	2.960 (2.726 to 3.214)	2.410 (2.057 to 2.825)	2.898 (2.631 to 3.194)
Surgeon characteristics				
Physician sex				
Female	0.920 (0.698 to 1.211)	1.103 (0.930 to 1.308)	0.967 (0.648 to 1.441)	0.888 (0.693 to 1.139)
Male	Ref.	Ref.	Ref.	Ref.
Time since graduating from medical school				
0-10 yr	1.087 (0.966 to 1.222)	1.159 (1.073 to 1.251)	0.964 (0.846 to 1.099)	1.137 (1.050 to 1.230)
11-20 yr	1.020 (0.955 to 1.089)	1.101 (1.054 to 1.151)	0.962 (0.882 to 1.049)	1.051 (0.995 to 1.109)
21-30 yr	1.037 (0.977 to 1.101)	1.079 (1.036 to 1.122)	1.000 (0.921 to 1.085)	1.047 (0.994 to 1.103)
≥31 yr	Ref.	Ref.	Ref.	Ref.
Unknown	1.119 (0.894 to 1.401)	1.081 (0.926 to 1.261)	0.880 (0.661 to 1.170)	0.945 (0.793 to 1.126)
Region				
Midwest	0.987 (0.929 to 1.049)	0.997 (0.957 to 1.039)	0.893 (0.823 to 0.969)	0.955 (0.908 to 1.006)
Northeast	0.769 (0.715 to 0.827)	0.840 (0.801 to 0.882)	0.702 (0.641 to 0.769)	0.816 (0.771 to 0.862)
South	Ref.	Ref.	Ref.	Ref.
West	0.852 (0.788 to 0.922)	0.861 (0.817 to 0.908)	0.710 (0.644 to 0.784)	0.771 (0.725 to 0.819)
Other	0.296 (0.070 to 1.252)	0.952 (0.521 to 1.738)		
Urban				
Rural	0.977 (0.902 to 1.058)	1.027 (0.974 to 1.083)	0.998 (0.883 to 1.127)	1.040 (0.965 to 1.121)
Urban	Ref.	Ref.	Ref.	Ref.

continued

TABLE V (*continued*)

	Odds Ratio (95% CI) for Readmission to Hospital			
	Within 30 Days After Knee Replacement	Within 180 Days After Knee Replacement	Within 30 Days After Hip Replacement	Within 180 Days After Hip Replacement
Annual patient volume†				
1st quartile	Ref.	Ref.	Ref.	Ref.
2nd quartile	0.982 (0.920 to 1.047)	0.995 (0.953 to 1.038)	0.896 (0.824 to 0.974)	0.950 (0.902 to 1.000)
3rd quartile	0.925 (0.864 to 0.991)	0.931 (0.889 to 0.974)	0.839 (0.768 to 0.917)	0.904 (0.855 to 0.955)
4th quartile	0.860 (0.800 to 0.926)	0.925 (0.880 to 0.974)	0.737 (0.668 to 0.814)	0.811 (0.762 to 0.863)
Fellowship training				
No	0.998 (0.946 to 1.054)	1.023 (0.986 to 1.060)	1.018 (0.944 to 1.098)	0.963 (0.918 to 1.010)
Yes	Ref.	Ref.	Ref.	Ref.
Board certification				
No	0.992 (0.927 to 1.061)	0.977 (0.934 to 1.023)	1.038 (0.948 to 1.137)	1.005 (0.949 to 1.064)
Yes	Ref.	Ref.	Ref.	Ref.
State license				
No	1.191 (0.974 to 1.457)	1.140 (0.994 to 1.309)	1.189 (0.939 to 1.505)	1.080 (0.930 to 1.255)
Yes	Ref.	Ref.	Ref.	Ref.
Malpractice claim				
No	Ref.	Ref.	Ref.	Ref.
Yes	1.072 (1.019 to 1.128)	1.077 (1.041 to 1.115)	1.096 (1.024 to 1.174)	1.098 (1.052 to 1.146)

*Surgeons with <11 procedures per year were not included in this study, per the Medicare data use agreement. †Knee replacement surgeon annual volume: quartile 1, 11 to 18.9 patients; quartile 2, 19 to 30.7 patients; quartile 3, 30.8 to 50.9 patients; quartile 4, ≥51 patients. Hip replacement surgeon annual volume: quartile 1, 11 to 18.9 patients; quartile 2, 19 to 30.3 patients; quartile 3, 30.4 to 49.1 patients; quartile 4, ≥49.2 patients.

with a higher likelihood of readmission within 30 days of the index surgery: greater patient age (odds ratio [OR] = 1.51 [95% CI: 1.44 to 1.58] for 75 to 84-year-olds and OR = 1.94 [95% CI: 1.79 to 2.10] for ≥85-year-olds compared with the 65 to 74-year age group), male sex (OR = 1.28 [95% CI: 1.22 to 1.33]), and greater Charlson Comorbidity Index (OR range: 1.40 to 2.40). The following surgeon characteristics were associated with a lower likelihood of readmission: practice in the Northeast (OR = 0.77 [95% CI: 0.72 to 0.83]) and West regions (OR = 0.85 [95% CI: 0.79 to 0.92]), and higher patient volume (OR = 0.86 [95% CI: 0.80 to 0.93]). Surgeons who had any malpractice claim were also associated with readmission (OR = 1.07 [95% CI: 1.02 to 1.13]). Similar associations were found between the patient and surgeon characteristics and readmission within 180 days (Table V).

Hip Replacement

In the multivariable logistic model adjusted for patient and surgeon characteristics, the following factors were associated with a higher likelihood of readmission within 30 days of the index surgery: greater patient age (OR = 1.34 [95% CI: 1.26 to 1.42] for 75 to 84-year-olds and OR = 1.95 [95% CI: 1.78 to 2.13] for ≥85-year-olds compared with the 65 to 74-year age group) and greater Charlson Comorbidity Index (OR range: 1.37 to 2.41). The following surgeon characteristics were associated with a lower likelihood of readmission: practice in the Northeast (OR = 0.70 [95% CI: 0.64 to 0.77]), Midwest (OR = 0.89 [95% CI: 0.82 to 0.97]), and West regions (OR = 0.71 [95% CI: 0.64 to 0.78]), and higher patient volume (OR range: 0.74 to 0.90). Surgeons who had any malpractice claim were also associated with readmission (OR = 1.10 [95% CI: 1.02 to 1.17]). Female sex was also associated with readmission within 180 days from the index surgery (OR = 0.95 [95% CI: 0.92 to 0.99]) (Table V).

Discussion

This study of 2 common orthopaedic procedures used a nationally representative database to identify patient and surgeon factors that were associated with surgical and postoperative costs and readmission. Patient characteristics that included greater age and a higher Charlson Comorbidity Index were associated with both higher surgical costs and readmission. Additionally, surgeon characteristics that included lower patient volume and Northeast and West practice region were associated with greater surgical costs and readmission. Notably, surgeon malpractice claims were associated with hospital readmission.

Previous studies have shown that higher surgical volume is associated with lower postoperative complication risk and costs[3,21-23]. Our results revealed a similar pattern, as patients treated by surgeons with a high volume had significantly lower costs for the index surgery and for 30 and 180-day episode-based bundle costs for both total knee replacement and hip replacement. A similar study among urologists suggested that high-volume surgeons could potentially minimize costs, by avoiding the use of unnecessary

medical supplies, because of their familiarity with the procedures[21]. High practice volumes also suggest more cost-efficient procedure, which was also aligned with our findings. These findings could guide medical payers and provider networks by suggesting that higher-volume surgeons and centers would provide patients with financial and postoperative outcome benefits.

Our study builds on existing literature on the association between surgeon volume and readmission rates by analyzing the relationship of readmission rates to several additional factors, including years since graduating from medical school, fellowship training, board certification, and malpractice claims. We found that patients had a greater risk of readmission if the procedure was performed by one of the surgeons with a malpractice claim, slightly more than one-third of the cohort. Additionally, patients who underwent TKR performed by surgeons who had graduated from medical school <31 years previously had a higher 180-day risk of readmission compared with the patients of surgeons who had been in practice ≥31 years.

This study had several important limitations. First, the analysis was limited to the Medicare population: it was only capable of identifying and evaluating patients covered by Medicare and surgeons who accept Medicare. Second, as with other studies based on national administrative claims data, it lacked information on the patients' clinical indicators and disease severity. Third, Medicare reimbursement could vary among different hospitals. Fourth, the costs associated with surgery may also vary among patients due to their individual health conditions. In other words, we identified all costs during the index surgery, which may be an overestimate for those patients who underwent treatment for other conditions at the same time. Finally, we did not account for hospital-level factors or investigate the postoperative complications leading to readmission to determine whether their cause was related to the index surgery.

In conclusion, higher orthopaedic surgeon patient volume was associated with lower overall costs and readmission rates. Our study suggests that additional factors such as surgeons' annual patient volume and malpractice history are relevant when choosing a surgeon for an orthopaedic procedure. Information on surgeons' malpractice claims and annual volume should be made publicly available to assist patients in the surgeon selection process. These results could be used to inform future guidelines of medical payers and provider networks in order to improve health-care outcomes and support value-based care initiatives. ■

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