Provider volumes and early outcomes of primary total joint replacement in Ontario

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Background: A relation between provider volume and outcome of total joint replacement (TJR) has not been demonstrated in Canada. Given the recent increase in TJR, changing patient characteristics and small sizes of previous Ontario studies, we reassessed whether adverse outcomes of TJR are related to hospital and surgeon procedure volumes.

Methods: We included all Ontarians aged 20 years and older who underwent a unilateral elective primary total hip replacement (THR) or total knee replacement (TKR) between April 2000 and March 2004. The main data sources were hospital discharge abstracts and physician billings. We defined provider volume as the average annual number of primary and revision procedures performed by hospitals and surgeons during the study period. We assessed the association between procedure volumes and acute length of hospital stay (ALOS) and between volume and rate of surgical complications during the index admission; death within 90 days of operation; readmission for amputation, fusion or excision within 1 year; and revision arthroplasty within 1 year. We adjusted for age, sex, comorbidity, arthritis type, teaching hospital status and discharge disposition. The analyses of hospital volume were adjusted for surgeon volume and vice versa.

Results: We included 20 290 patients who received THR and 27 217 who received TKR. Patient age, sex and comorbidity were significant predictors of complications and mortality. There were no associations between provider volume and mortality. Findings for other outcomes were mixed. Surgeon procedure volume was related to rates of revision THR but not to rates of revision TKR. Shorter ALOS was associated with male sex, younger age, fewer comorbidities, discharge to a rehabilitation unit or facility and greater surgeon volume.

Conclusion: Patient characteristics were significant predictors of complications, ALOS and mortality after primary TJR. Evidence for a relation between provider volume and outcome was limited and inconsistent.

Contexte : On n'a pas démontré de lien, au Canada, entre le volume des interventions pratiquées et les résultats de l'arthroplastie totale. Étant donné l'augmentation récente du nombre d'arthroplasties totales, l'évolution des caractéristiques des patients et l'envergure limitée des études réalisées auparavant en Ontario, nous avons voulu réévaluer la situation pour voir s'il existe un lien entre les résultats indésirables de l'arthroplastie totale et le volume des interventions pratiquées par les hôpitaux et les chirurgiens.

Méthodes : Nous avons inclus tous les Ontariens de 20 ans et plus qui ont subi une arthroplastie totale de la hanche (ATH) ou du genou (ATG) primaire élective unilatérale entre avril 2000 et mars 2004. Les résumés de congé de l'hôpital et les factures des médecins ont constitué les principales sources de données. Nous avons défini le volume des interventions pratiquées par le fournisseur comme étant le nombre annuel moyen d'interventions primaires et de révisions pratiquées par les hôpitaux et les chirurgiens au cours de la période à l'étude. Nous avons analysé le lien entre les volumes d'interventions et la durée de l'hospitalisation en milieu de soins actifs (DMS) et entre le volume et le taux de complications chirurgicales au cours de l'admission témoin, les décès dans les 90 jours de l'intervention, la réadmission pour une amputation, une fusion ou une excision dans l'année, et l'arthroplastie de révision dans l'année. Nous avons tenu compte de l'âge, du sexe, de la présence d'une comorbidité, du type d'arthrite, du statut d'hôpital d'enseignement et du résultat au congé. Les analyses du volume des interventions pratiquées à l'hôpital ont été rajustées en fonction du volume des interventions pratiquées par le chirurgien et vice versa.

Résultats : Nous avons inclus 20 290 patients qui ont subi une ATH et 27 217 qui ont subi une ATG. L'âge et le sexe du patient et la présence d'une comorbidité constituaient des prédicteurs importants de complications et de mortalité. Il n'y avait aucun lien entre le volume des interventions pratiquées par le fournisseur et la mortalité Les constatations dans le cas d'autres résultats ont été mixtes. On a établi un lien entre le volume des interventions pratiquées par le chirurgien et les taux d'ATH de révision, mais non les taux d'ATG de révision. On a établi un lien entre une DMS plus courte et le sexe masculin, l'âge plus jeune, la présence de comorbidités moins nombreuses, le transfert à un service ou un établissement de réadaptation et le volume plus élevé d'interventions pratiquées par le chirurgien.

Conclusion : Les caractéristiques des patients constituaient d'importants prédicteurs de complications, de DMS et de mortalité après une arthroplastie totale primaire. Les preuves d'un lien entre le volume des interventions pratiquées par le fournisseur et le résultat ont été limitées et erratiques.

Total joint replacements (TJRs) are among the most frequently performed surgical procedures in the world, and the number performed annually has increased steadily over the last decade. Between 1995 and 2005, the annual number of total hip replacements (THRs) grew by over 50% in Ontario, and the annual number of total knee replacements (TKRs) roughly doubled.[1] The age-standardized rates per 100 000 increased from 62 to 75 for THR and from 59 to 107 for TKR.[2] Although the greatest increases were among patients aged 85 years and older,[2] the growth in TJR has had more to do with demand and funding than with population aging. In many jurisdictions, the last decade has also seen considerable rationalization of hospital-based care. In Ontario, for example, many hospitals were closed or merged to reduce the number of facilities and to increase surgical volumes.[3] Consequently, annual volumes of TJR have increased for both hospitals and surgeons.

Some evidence suggests that a patient's outcome after surgery is at least partially related to the number of procedures performed by the operating hospital and surgeon.[4–6] Some have suggested that patient complications and mortality could be minimized by assigning certain procedures, including TJR, to regional centres of excellence, arguing that more experienced providers make more appropriate decisions about the indications and risks for surgery. Further, rehabilitation and other important ancillary services may be more accessible to higher-volume providers.

In contrast to American studies,[7–10] associations between provider volumes and outcomes of THR have not been shown in Ontario,[11] and for only one outcome (revision arthroplasty) has the relation been observed after TKR.[12] Given the growing demand for TJR, the changing characteristics of patients and the small size of previous studies, we believed that it was time to reassess the relation between provider volume and adverse outcomes of TJR in Ontario. We studied 4 outcomes: surgical complications during the index admission; death within 90 days of operation; readmission for amputation, fusion or excision within 1 year; and revision arthroplasty within 1 year.

Methods

Data sources and patients

Data for the study were obtained through the Institute for Clinical Evaluative Sciences (www.ices.on.ca). The main data sources were hospital discharge abstracts provided by the Canadian Institute for Health Information (CIHI) and physician billings from the Ontario Health Insurance Plan (OHIP).

Our study cohorts included all patients who underwent THR or TKR between Apr. 1, 2000, and Mar. 31, 2004. Because neither CIHI data nor OHIP data consistently identified the laterality of the joint replaced, we restricted our study to individuals who had their first planned primary THR or TKR during the study period, and we excluded those who had a subsequent primary joint replacement during follow-up. We excluded non-Ontario residents, people under 20 years of age and procedures that were "cancelled," "out-of-hospital" or "abandoned after onset." To further increase homogeneity, we also excluded patients who had bilateral procedures.

Patients were identified using specific procedure codes recorded on the hospital discharge abstract. Data through Mar. 31, 2002, were coded by use of the International Classification of Diseases, version 9 (ICD-9) and the Canadian Classification of Diagnostic, Therapeutic and Surgical Procedures (CCP). The ICD version 10 and the Canadian Classification of Health Interventions (CCI) were implemented Apr. 1, 2002. The ICD-9/CCP codes for primary THR are 93.51 and 93.59. The corresponding code for primary TKR is 93.41. The ICD-10/CCI codes for hip and knee replacement are 1.VA.53 and 1.VG.53, respectively, with subcodes specifying the implant components and surgical approach. For hips, we included only dual-component procedures. Joint replacements for cancer, fractures or trauma were considered unplanned and were excluded. We deemed procedures unplanned if a record identified a hospital admission as "urgent," "emergent" or "entry from emergency," or if it was accompanied by a

diagnosis code listed in Appendix 1 (available at www.cma.ca/cjs). We also excluded patients whose codes indicated a preexisting joint infection.

The research protocol was approved by the research ethics board at Sunnybrook Health Sciences Centre in Toronto.

Procedure volume classification

We identified the primary surgeon associated with each procedure by matching the hospital discharge abstract with the corresponding OHIP bill. We determined surgeon volume by counting all procedures performed over the study period (without applying exclusion criteria) and computing the mean annual volume for each surgeon. We divided surgeons performing THR into 4 volume categories based on the quartile distribution of patients: 2–25, 26–40, 41–60 and 61 or more procedures per annum. This distributed patients approximately equally among the volume categories. We excluded surgeons who performed fewer than 2 procedures per annum to minimize the impact of potential coding errors. The corresponding cut-points for TKR were: 2–35, 36–40, 51–70 and 71 or more procedures per annum. We calculated hospital volume categories in a similar way, and we excluded hospitals that performed fewer than 10 procedures per annum.

Patient outcomes

All patients were followed for 1 year from the date of surgery. The study outcomes were surgical complications that occurred during the index admission; death within 90 days of operation; a composite of readmission for amputation, fusion or excision within 1 year; readmission for revision arthroplasty within 1 year; and acute hospital length of stay (ALOS). We limited follow-up to 1 year because previous research found little evidence of a relation between surgeon procedure volume and THR failure much beyond this.[10] We identified death within 90 days of operation using the OHIP Registered Persons Database. We grouped together operative complications, which included infections and inflammatory reactions, hemorrhage, vascular complications, respiratory complications, mechanical complications of the prosthesis and complications of the anesthesia (Appendix 2, available at www.cma.ca/cjs) because of the rarity of the individual events. We identified revision procedures using 2 different methods. For procedures performed during 2002/03–2004/05, we used ICD-10-CA/CCI procedure codes accompanied by the supplementary status attribute "R." For procedures performed before this, we used ICD-9/CCP procedure codes specifically for revisions: 93.52 and 93.53 for THR and 93.40 for TKR. Finally, we recorded transfers to rehabilitation units and ALOS (date of admission to date of transfer or discharge) for each index admission.

Patient and hospital characteristics

Surgical outcomes are related to patients' demographic and clinical characteristics. We obtained demographic information from the OHIP Registered Persons Databases. We used a modification of the protocol developed by Shipton and colleagues[13] to identify whether patients had a history of rheumatoid arthritis. Comorbidities listed on hospital discharge abstracts in the 5 years before the index admission were coded according to adaptations of the Charlson Comorbidity Index.[14,15] Members of the Council of Academic Hospitals of Ontario (www.cahohospitals.com) were defined as teaching hospitals. We included these factors in analyses of effects of procedure volume on outcome to adjust for potential confounding.

Statistical analyses

We treated the outcome variables as indicators of whether each patient experienced an event of interest and examined each outcome separately. Ordinary linear or logistic regression requires that all observations are statistically independent. Because our data were clustered, we used generalized estimating equations suitable for correlated data.[16,17] In the multivariable analyses, we used ordinal procedure volume variables to adjust the hospital volume analyses for surgeon volume and vice versa. We tested for interactions among the covariates, but none were significant. We described associations between outcomes and provider volumes using odds ratios (ORs) and 95% confidence intervals (95% CIs).

We assessed the impact of provider volume and covariates on the relative change in mean ALOS (in days) through multivariable analysis of rate ratios.

Because the duration of follow-up was long for 2 outcomes (revision arthroplasty and the composite outcome of amputation, fusion and excision), we repeated our analyses for these outcomes using time-to-event methods. We used the Kaplan–Meier approach to estimate failure-free survival and Cox proportional hazards models to adjust for patient and provider characteristics. We removed patient data from the analysis if they died, left the province or became ineligible for OHIP. In these analyses, we describe the associations between outcomes and provider volumes using hazard ratios and 95% CIs.

All analyses were performed using SAS version 9.1 for UNIX (SAS Institute) with the type I error probability (α) set at 0.05.

RESULTS

Cohort characteristics

Between Apr. 1, 2000, and Mar. 31, 2004, Ontario surgeons performed 30 917 THRs and 39 978 TKRs. About

one-third of the cases were excluded from our study, largely because patients had prior joint replacements or had a subsequent primary joint replacement during follow-up (Table 1).

Primary THRs were performed in 68 hospitals, but we excluded 6 facilities that averaged fewer than 10 procedures per year (14 procedures in total). Primary TKRs were performed in 67 facilities, 2 of which averaged fewer than 10 procedures per year (accounting for 3 procedures). Most hospitals (62 for hip and 65 for knee) performed joint replacement procedures in each of the 4 years studied.

In total, 267 surgeons performed THR, and 280 surgeons performed TKR. Excluding surgeons who averaged fewer than 2 procedures per year resulted in 261 hip surgeons and 274 knee surgeons. In total, 76% of the surgeons performed primary TJR in each year studied.

The final study cohort comprised 47 507 patients: 20 290 who had a THR and 27 217 who had a TKR. These patients represent two-thirds of those who had TJR during the study period.

Tables 2 and 3 give the distributions of THR and TKR by surgeon and hospital volume category. In all, 17% of THRs and 15% of TKRs were performed by top-volume surgeons in top-volume hospitals, and 9% of THRs and just over 7% of TKRs were performed by the lowest-volume surgeons in the lowest-volume hospitals.

Table 1. Selection of patients for inclusion

Entry criteria	Joint operated on; no. (%)	
	Hip	Knee
Inclusion		
Procedures performed Apr. 1, 2000, to Mar. 31, 2004	30 917 (100)	39 978 (100)
Exclusion		
Unplanned joint replacement, age < 20 yr, or non-Ontario resident	2 536 (8.2)	776 (1.9)
Subsequent primary total joint replacement during the accrual period	2 906 (9.4)	4 925 (12.3)
Prior joint replacement (dating back to Apr. 1, 1991)	2 982 (9.6)	4 312 (10.8)
Revision procedure	2 033 (6.6)	1 766 (4.4)
Multijoint (including bilateral) procedures	121 (0.4)	917 (2.3)
Joint infection on admission	13 (0.0)	16 (0.0)
Procedure abandoned after onset	7 (0.0)	7 (0.0)
Multiple "primary" surgeons	9 (0.0)	30 (0.1)
Performed in a hospital with an annual average of < 10 procedures	14 (0.0)	3 (0.0)
Performed by a surgeon with an annual average of < 2 procedures	6 (0.0)	9 (0.0)
Final cohort	20 290 (65.6)	27 217 (68.1)

Table 2. Distribution of 20 290 patients who underwent elective primary hip replacement, by average annual hospital and surgeon procedure volume

Hospital volume, no. of hip replacements (no. of hospitals)	Surgeon volume, no. of hip replacements (no. of surgeons); no. (%) of patients				
	2–25 (*n* = 133)	(26–40) (*n* = 73)	41–60 (*n* = 33)	> 60 (*n* = 22)	Total (*n* = 261)
10–110 (*n* = 31)	1 849 (9.1)	2 079 (10.2)	963 (4.7)	412 (2.0)	5 303 (26.1)
111–150 (*n* = 16)	1 271 (6.3)	2 460 (12.1)	1 086 (5.4)	583 (2.9)	5 401 (26.6)
151–225 (*n* = 10)	1 098 (5.4)	1 675 (8.3)	1 509 (7.4)	523 (2.6)	4 805 (23.7)
> 225 (*n* = 5)	261 (1.3)	348 (1.7)	673 (3.3)	3 499 (17.2)	4 781 (23.6)
Total (*n* = 62)	4 479 (22.1)	6 562 (32.3)	4 231 (20.8)	5 018 (24.7)	20 290

Table 3. Distribution of 27 217 patients who underwent elective primary total knee replacement, by average annual hospital and surgeon procedure volume

Hospital volume, no. of knee replacements (no. of hospitals)	Surgeon volume, no. of knee replacements (no. of surgeons); no. (%) of patients				
	2–35 (*n* = 145)	36–50 (*n* = 57)	51–70 (*n* = 45)	> 70 (*n* = 27)	Total (*n* = 274)
10–130 (*n* = 31)	2 009 (7.4)	2 360 (8.7)	1 704 (6.3)	726 (2.7)	6 799 (25.0)
131–180 (*n* = 16)	1 691 (6.2)	2 313 (8.5)	2 152 (7.9)	526 (1.9)	6 682 (24.6)
181–270 (*n* = 11)	1 527 (5.6)	1 147 (4.2)	2 321 (8.5)	1 604 (5.9)	6 599 (24.3)
> 270 (*n* = 7)	1 341 (4.9)	717 (2.6)	994 (3.7)	4 085 (15.0)	7 137 (26.2)
Total (*n* = 65)	6 568 (24.2)	6 537 (24.0)	7 171 (26.3)	6 941 (25.5)	27 217

Outcomes

Table 4 describes the study cohorts and provides crude outcome event rates according to patient characteristics and provider volumes.

Surgical complications during the index admission

The crude rates for in-hospital surgical complications were slightly higher for THR (60 per 1000 patients) than for TKR (47 per 1000 patients) (Table 4). In adjusted analyses, complications associated with hip and knee replacement increased with age and were more frequent in men (Table 5). Complication rates increased with comorbidity in hip replacement patients but not in knee replacement patients.

Whereas there was some variation in crude rates for in-hospital complications by provider volume category (Table 4), after adjustment for potential confounders, complication rates were not related to hospital procedure volume (Table 5). In contrast, surgeons with the lowest-quartile THR volumes had about 30% higher complication rates than surgeons in the higher-volume quartiles. However, no such relation was observed for TKR.

Table 4. Crude outcome event rates, by patient and hospital characteristic and surgeon procedure volume

			Number of events per 1000 patients							
	Cohort, no. (%) of patients		Surgical complication during index admission		Death within 90 d		Readmission for amputation, fusion or excision within 1 yr		Readmission for revision arthroplasty within 1 yr	
Characteristic	Hip, *n* = 20 290	Knee, *n* = 27 217	Hip, *n* = 1 208	Knee, *n* = 1 280	Hip, *n* = 122	Knee, *n* = 144	Hip, *n* = 51	Knee, *n* = 115	Hip, *n* = 340	Knee, *n* = 301
Total			59.54	47.03	6.01	5.29	2.51	4.23	16.76	11.06
Patient age, yr										
20–29	108 (0.5)	16 (0.1)	64.81	62.50	0.00	0.00	0.00	62.50	27.78	62.50
30–39	362 (1.8)	78 (0.3)	80.11	25.64	0.00	0.00	8.29	12.82	27.62	25.64
40–49	1 301 (6.4)	691 (2.5)	51.50	47.76	0.77	1.45	3.84	14.47	15.37	34.73
50–59	3 038 (15.0)	3 866 (14.2)	41.47	37.25	0.99	1.03	1.97	5.43	16.79	17.33
60–69	5 569 (27.4)	8 642 (31.8)	54.41	39.23	3.95	2.66	2.69	4.28	13.83	9.95
70–79	7 227 (35.6)	10 913 (40.1)	59.36	51.86	6.23	5.59	1.94	3.30	17.16	9.16
80–89	2 580 (12.7)	2 961 (10.9)	89.53	63.09	17.83	18.22	3.10	3.04	20.93	6.75
> 90	105 (0.5)	50 (0.2)	152.38	160.00	47.62	20.00	0.00	0.00	9.52	20.00
Patient sex										
Male	8 630 (42.5)	10 285 (37.8)	63.73	55.91	7.65	7.78	2.90	5.83	15.87	13.03
Female	11 660 (57.5)	16 932 (62.2)	56.43	41.58	4.80	3.78	2.23	3.25	17.41	9.86
Patient comorbidity, Charlson index										
No hospitalization	17 483 (86.2)	23 833 (87.6)	55.37	45.53	4.92	4.74	2.40	3.69	15.79	10.24
0	1 749 (8.6)	2 079 (7.6)	78.90	58.20	10.29	6.73	2.29	7.70	20.01	17.32
1	629 (3.1)	827 (3.0)	101.75	55.62	9.54	9.67	3.18	8.46	33.39	15.72
≥ 2	429 (2.1)	478 (1.8)	53.61	56.49	16.32	18.83	6.99	8.37	11.66	16.74
Patient's arthritis type										
Rheumatoid	2 641 (13.0)	3 805 (14.0)	56.80	45.99	7.95	4.99	2.27	3.68	18.55	12.61
Other	17 649 (87.0)	23 412 (86.0)	59.95	47.20	5.72	5.38	2.55	4.31	16.49	10.81
Patient discharge disposition										
Rehabilitation unit or facility	7 848 (38.7)	10 572 (38.8)	58.74	44.84	3.31	2.27	1.53	4.35	17.71	11.16
Other	12 442 (61.3)	16 645 (61.2)	60.04	48.36	7.72	7.21	3.13	4.15	16.15	10.99
Hospital teaching status										
Teaching	7 362 (36.3)	8 471 (31.1)	69.82	56.07	5.16	5.08	4.35	3.31	16.30	10.62
Other	12 928 (63.7)	18 746 (68.9)	53.68	42.89	6.50	5.39	1.47	4.64	17.02	11.26
Hospital procedure volume; hip, knee										
10–110, 10–130	5 303 (26.1)	6 799 (25.0)	49.41	37.36	6.22	5.44	2.26	6.62	17.91	15.15
111–150, 131–180	5 401 (26.6)	6 682 (24.6)	56.10	56.87	7.04	5.54	1.85	3.44	15.55	10.48
151–225, 181–270	4 805 (23.7)	6 599 (24.3)	72.22	45.92	5.20	5.91	1.25	3.18	16.23	10.00
> 225, > 270	4 781 (23.6)	7 137 (26.2)	61.91	47.92	5.44	4.34	4.81	3.64	17.36	8.69
Surgeon procedure volume; hip, knee										
2–25, 2–35	4 479 (22.1)	6 568 (24.2)	69.88	42.17	7.37	6.24	2.01	5.94	21.21	12.79
26–40, 36–50	6 562 (32.3)	6 537 (24.0)	50.14	54.31	5.49	4.74	2.59	3.06	14.93	10.10
41–60, 51–70	4 231 (20.8)	7 171 (26.3)	55.78	46.16	5.67	4.74	1.89	3.90	17.25	12.13
> 60, > 70	5 018 (24.7)	6 941 (25.5)	65.76	45.53	5.78	5.47	3.39	4.03	14.75	9.22

Death within 90 days of operation

In all, 122 hip patients (6.0 per 1000) and 144 knee patients (5.3 per 1000) died within 90 days of operation. The death rates increased with age and comorbidity, and the rates were higher for men than for women. There were slight trends toward decreasing mortality as hospital and surgeon volumes increased, but the reductions in the crude rates were small.

Table 5 shows the adjusted odds of death within 90 days of operation. The adjusted results confirm that age, sex and comorbidity were strong predictors of 90-day mortality. However, neither hospital procedure volume nor surgeon procedure volume were significant predictors of death within 90 days of operation.

Readmissions for amputation, fusion or excision within 1 year

About 0.7% of knee replacement patients less than 50 years of age were readmitted for an amputation, fusion or excision, which was a markedly higher rate than among older patients (Table 4). The relation remained significant after adjustment for covariates (Table 5). Whereas there was a similar, less pronounced trend for THR (Table 4), it did not persist after adjustment for covariates (Table 5).

The results by provider volume were mixed. Hospitals in the third-highest volume category had significantly lower odds for readmission following both hip and knee replacement (Table 5). The outcome also was sensitive to surgeon volume for knee replacement but not for hip replacement.

The THR patients admitted to teaching hospitals had a nearly 4-fold greater odds of readmission than patients admitted to nonteaching hospitals, even after adjustment for case mix (Table 5). This was not true for TKR.

Readmissions for revision arthroplasty within 1 year

The crude revision rate over 1 year was 1.6% for THR and 1.1% for TKR (Table 4). Revision rates were higher for younger patients and tended to decline with age. After adjustment for covariates, TKR revision rates varied by age and sex, but neither age nor sex were significant predictors of revision after THR (Table 5).

Table 5. Adjusted odds ratios for outcomes after total hip or knee replacement, by patient and hospital characteristic and surgeon procedure volume

	Adjusted* odds ratio (95% confidence interval)							
	Surgical complication during index admission		Death within 90 d		Readmission for amputation, fusion or excision within 1 yr		Readmission for revision arthroplasty within 1 yr	
Characteristic	Hip	Knee	Hip	Knee	Hip	Knee	Hip	Knee
Patient age (yr)	1.02† (1.01–1.02)	1.02† (1.01–1.03)	1.11† (1.08–1.13)	1.11† (1.08–1.14)	0.99 (0.97–1.01)	0.96† (0.94–0.98)	1.00 (0.99–1.01)	0.96† (0.95–0.97)
Patient sex (male v. female)	1.20† (1.04–1.39)	1.39† (1.23–1.58)	2.13† (1.52–2.97)	2.11† (1.42–3.12)	1.23 (0.65–2.34)	1.75† (1.17–2.61)	0.92 (0.73–1.15)	1.34† (1.02–1.75)
Patient comorbidity (Charlson index v. absent or 0)								
1	1.66† (1.26–2.18)	1.08 (0.70–1.66)	1.42 (0.67–3.00)	1.68 (0.77–3.65)	1.33 (0.41–4.29)	2.11† (1.01–4.40)	2.05† (1.35–3.11)	1.44 (0.75–2.77)
≥ 2	1.56† (1.16–2.11)	1.13 (0.74–1.71)	3.82† (2.07–7.05)	3.20† (1.59–6.46)	2.94 (0.76–11.45)	2.05 (0.90–4.66)	1.13 (0.53–2.38)	1.54 (0.72–3.31)
Patient's arthritis type (rheumatoid v. other)	0.99 (0.84–1.17)	1.04 (0.87–1.24)	1.57 (0.89–2.77)	1.00 (0.60–1.67)	0.85 (0.44–1.66)	0.85 (0.50–1.44)	1.11 (0.82–1.51)	1.08 (0.78–1.50)
Hospital teaching status (teaching v. other)	1.78 (0.91–3.45)	1.68† (1.11–2.56)	0.74 (0.41–1.36)	1.17 (0.85–1.61)	3.81† (2.12–6.87)	0.65 (0.35–1.19)	0.95 (0.59–1.54)	1.18 (0.83–1.68)
Hospital procedure volume (mean no. per yr v. hip 10–110, knee 10–130)								
111–150, 131–180	1.09 (0.68–1.73)	1.52 (0.98–2.36)	1.19 (0.76–1.87)	1.07 (0.72–1.59)	0.76 (0.33–1.73)	0.51 (0.20–1.29)	0.92 (0.60–1.41)	0.64 (0.39–1.04)
151–225, 181–270	1.26 (0.62–2.57)	1.24 (0.81–1.91)	0.90 (0.55–1.49)	1.05 (0.75–1.48)	0.40† (0.18–0.88)	0.50† (0.27–0.93)	0.94 (0.67–1.33)	0.62† (0.42–0.91)
> 225, > 270	0.67 (0.34–1.30)	0.97 (0.63–1.50)	1.22 (0.53–2.78)	0.69 (0.39–1.23)	0.76 (0.24–2.40)	0.69 (0.33–1.44)	1.34 (0.71–2.52)	0.50† (0.34–0.72)
Surgeon procedure volume (mean no. per yr v. hip 2–25, knee 2–35)								
26–40, 36–50	0.73† (0.60–0.87)	1.30† (1.05–1.60)	0.72 (0.47–1.09)	0.76 (0.53–1.09)	1.33 (0.61–2.90)	0.54† (0.33–0.88)	0.72† (0.54–0.96)	0.73 (0.53–1.01)
41–60, 51–70	0.75† (0.63–0.90)	1.03 (0.87–1.24)	0.79 (0.48–1.29)	0.75 (0.48–1.16)	0.56 (0.21–1.49)	0.73 (0.43–1.24)	0.80 (0.58–1.10)	0.92 (0.65–1.31)
> 60, > 70	0.67† (0.55–0.82)	0.90 (0.67–1.19)	1.00 (0.52–1.93)	1.02 (0.63–1.67)	0.62 (0.37–1.06)	0.81 (0.41–1.62)	0.58† (0.42–0.79)	0.75 (0.51–1.09)

*Adjusted for patient age, sex, comorbidity and arthritis type, hospital teaching status, hospital procedure volume, and surgeon procedure volume.
†Significant at $p < 0.05$.

The results for provider volume were mixed. Surgeon volumes were statistically related to revision THR but not to revision TKR (Table 5). Surgeons with the lowest-quartile volumes had roughly 30% and 40% higher revision rates than surgeons in the second- and highest-volume quartiles, respectively, but did not differ statistically from surgeons in the third-volume quartile (Table 5).

Hospital procedure volumes were predictive of revision TKR but not of revision THR (Table 5). For knee replacement, hospitals in the lowest-volume quartile had the highest crude rates of revision, and after adjustment for confounding, the rates were significantly lower (by about 40% and 50%, respectively) for hospitals in the third- and highest-volume quartiles. For hips, the risk differences among hospital volume strata were small, and the CIs around the ORs were wide (Table 5).

Reanalysis using time-to-event methods confirmed the results (data not shown).

Length of acute hospital stay for the index admission

The mean ALOSs were 6.4 days for THR and 6.0 days for TKR. Stays were relatively shorter for the 38% of patients who were transferred to rehabilitation units or facilities (6.0 v. 6.7 days for THR; 5.4 v. 6.4 days for TKR). Table 6 presents the results after adjustment for case mix. The rate ratios for relative change in average ALOS increased with age and comorbidity for both THR and TKR, and women stayed relatively longer than men after THR but not after TKR. Higher-volume surgeons had relatively shorter ALOSs after both THR and TKR. However, no such associations were present with hospital volume.

Discussion

We found little consistent evidence for an important relation between provider volumes and early outcomes of elective primary TJR in Ontario. Our results are largely in keeping with previous Ontario research[11,12] but conflict with several American studies, which have consistently reported volume–outcome relations for TJR.[7–9,18–21] One possible explanation is that surgeon and hospital procedure volumes are relatively greater and exhibit less variation in Ontario. For instance, whereas half of US joint replacements are performed in hospitals with fewer than 100 procedures per year,[19,22] fewer than 20% are performed in such hospitals in Ontario.

Importantly, we found that rates of complications, even among lower-volume providers, were generally low and, where comparable, similar to or less than those in the United States. Overall, about 6 per 1000 Ontarians died within 90 days of joint replacement. This is roughly the same rate reported by Katz and colleagues[19] and Soohoo and colleagues[21] in US Medicare knee replacement patients, and about two-thirds that observed in a 1995 hip replacement cohort.[7] Our 1-year revision rates (about 1.5% for THR and 1% for TKR) are similar to those observed in the United States, United Kingdom, Australia and Sweden.[9,23,24] Taken together, our findings provide little support for regionalizing joint replacement surgery in Ontario. Even if consistent volume–outcome effects were observed, the small absolute improvements potentially achievable through regionalization would have to be weighed against other important considerations. Regionalization could make joint replacement procedures less accessible, particularly to rural patients, and could contribute to longer waiting times, neither of which would benefit patients.

Several of our findings were unexpected. In-hospital complications were more frequent with THR than with TKR, and complication rates increased with comorbidity for hip but not knee replacement. Similarly, THR (but not TKR) patients admitted to teaching hospitals had higher odds of readmission for amputation, fusion or excision relative to those admitted to nonteaching hospitals. Higher-volume surgeons had relatively shorter ALOSs after both procedures, but no such associations were observed for hospital volume. Previously, Kreder and colleagues[11,12] studied in-hospital complications and found associations with age and comorbidity for both THR and TKR. The fact that we

Table 6. Adjusted comparison of acute hospital length of stay after total hip or knee replacement, by patient and hospital characteristic and surgeon procedure volume

Characteristic	Adjusted* rate ratio (95% CI)			
	Hip		Knee	
Patient age (yr)	1.01†	(1.01–1.01)	1.01†	(1.01–1.01)
Patient sex (male v. female)	0.96†	(0.94–0.99)	0.98	(0.96–1.00)
Patient comorbidity (Charlson index v. missing or 0)				
1	1.19†	(1.11–1.28)	1.09†	(1.04–1.15)
≥ 2	1.38†	(1.22–1.56)	1.17†	(1.11–1.23)
Patient's arthritis type (rheumatoid v. other)	1.01	(0.98–1.04)	1.01	(0.99–1.03)
Patient discharge disposition (rehabilitation unit or facility v. other)	0.87†	(0.78–0.97)	0.85†	(0.77–0.94)
Hospital teaching status (teaching v. other)	1.17	(0.96–1.42)	1.05	(0.90–1.22)
Hospital procedure volume (mean no. per yr v. hip 10–110, knee 10–130)				
111–150, 131–180	0.97	(0.85–1.11)	0.99	(0.88–1.12)
151–225, 181–270	0.93	(0.74–1.17)	0.94	(0.78–1.15)
> 225, > 270	0.79	(0.61–1.00)	1.03	(0.78–1.35)
Surgeon procedure volume (mean no. per yr v. hip 2–25, knee 2–35)				
26–40, 36–50	0.93†	(0.89–0.98)	0.98	(0.94–1.02)
41–60, 51–70	0.93†	(0.88–0.98)	0.97	(0.94–1.01)
> 60, > 70	0.89†	(0.81–0.98)	0.93†	(0.88–0.98)

CI = confidence interval.
*Adjusted for patient age, sex, comorbidity and arthritis type, hospital teaching status, hospital procedure volume, and surgeon procedure volume.
†Significant at $p < 0.05$.

excluded a greater proportion of patients than Kreder and colleagues[11,12] may have contributed to the absence of such findings in our study. Age and comorbidity were important predictors of outcome in other studies of THR.[22,25–27]

There are several possible explanations for why teaching hospitals may have relatively higher complication rates. Patients referred to teaching hospitals may be surgically complex in ways that are not captured by standard measures of comorbidity. For example, teaching hospital surgeons may be more likely than others to operate on patients who have poor peripheral circulation, severe dysplasia, previous joint infection or metabolic bone disease. In addition, some complications in teaching hospitals may be attributable to physician trainees. In the only other Ontario study to consider TJR outcomes as a function of hospital teaching status, Coyte and colleagues[28] also found relatively higher revision rates in teaching hospitals. That multiple studies[22,23,29] have reported surgeon- but not hospital-volume effects on hip-replacement outcomes lends support to the notion that THR outcomes are particularly sensitive to surgical technique.

Relations between provider volume and length of hospital stay are complex. In earlier Ontario studies,[11,12] both higher-volume surgeons and higher-volume hospitals had relatively shorter average ALOSs. In a recent study of TJR in the United Kingdom, Judge and colleagues[30] also found relatively shorter lengths of stay in higher-volume trusts. These findings are consistent with the idea that higher-volume providers are more likely to employ policies or have access to resources (e.g., home care and rehabilitation services) that promote shorter ALOSs. As expected, we found that patients who were discharged to rehabilitation units or facilities had significantly shorter ALOSs. The fact that we did not observe a hospital-volume effect on ALOS is therefore most likely because of simultaneous adjustment for discharge destination. Future studies should consider whether joints replaced by higher-volume surgeons are less costly.

Strengths and limitations

To our knowledge, this is the largest Canadian study of TJR outcomes and the only one to report results for THR and TKR simultaneously. Whereas American studies have been confined largely to US Medicare recipients (who are aged 65 years and older), we included adults of all ages. This is important because several studies (including ours) have shown that younger age groups are at higher risk for revision arthroplasty, particularly after TKR.[27] Further, because most studies of joint failure have not had access to information about procedure laterality and have not excluded patients who had prior joint replacement, it has been impossible for these studies to definitively link outcomes to the index procedures. Here we reduced the potential for such misclassification by studying the first joint replaced during the accrual period and by excluding those who had prior or subsequent joint replacement.

Like most researchers who use administrative data, we had limited clinical information with which to assess patient outcomes, surgical complexity and comorbidity, and no information about patients' pain or functional status. Suboptimal patient-focused outcomes do not always result in surgical intervention. In fact, Katz and colleagues[31] found that patients who had TKR performed by low-volume surgeons in low-volume hospitals were twice as likely to have poor functional status as those operated on by high-volume surgeons in high-volume settings. This is an important dimension that is absent from studies of administrative data. Importantly, we also had no data about the reasons for revision procedures or cause of death.

Second, although evidence suggests that relations between provider volume and joint failure disappear after about 1 year,[9,10,23] we cannot comment on longer-term outcomes because we followed patients for only 1 year. Third, owing to the rarity of the clinical outcomes, we used a composite outcome measure for in-hospital complications, as well as for amputation, fusion or excision at 1 year. Despite the increased power, the CIs around the adjusted ORs were wide. Fourth, the large number of comparisons increased the probability of finding differences by chance. Thus, marginally significant differences should be viewed skeptically. Finally, we studied elective primary TJR. Our findings may not be generalizable to urgent procedures, revision procedures or partial joint replacements. Although adverse outcomes are relatively more frequent after revision arthroplasty,[7,10,22] in one study, volume–outcome associations with revision THR were less striking than with primary THR.[7] Given the growing burden of revision arthroplasty in Ontario, volume–outcome studies of these procedures are warranted.

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