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Resident Participation is Not Associated With Worse Outcomes After TKA

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Abstract

Background Approximately one-half of all US surgical procedures, and one-third of orthopaedic procedures, are performed at teaching hospitals. However, the effect of resident participation and their level of training on patient care for TKA postoperative physical function, operative time, length of stay, and facility discharge are unclear.

Questions/purposes (1) Are resident participation, postgraduate year (PGY) training level, and number of residents associated with absolute postoperative Patient-Reported Outcomes Measurement Information System (PROMIS®-10) global physical function score (PCS), and achieving minimum clinically important difference (MCID) PCS improvement, after TKA? (2) Are resident participation, PGY, and number of residents associated with increased TKA operative time? (3) Are resident participation, PGY, and number of residents associated with increased length of stay after TKA? (4) Are resident participation, PGY, and number of residents associated with higher odds of patients being discharged to another inpatient facility, rather than to their home (facility discharge)?

Methods We performed a retrospective study using a longitudinally maintained institutional registry of TKAs that included 1626 patients at a single tertiary academic institution from April 2011 through July 2016. All patients who underwent primary, elective unilateral TKA were included with no exclusions. All patients were included in the operative time, length of stay, and facility discharge models. The PCS model required postoperative PCS score (n = 1417; 87%; mean, 46.4; SD, 8.5) and the MCID PCS model required pre- and postoperative PCS (n = 1333; 82%; 55% achieved MCID). Resident participation was defined as named residents being present in the operating room and documented in the operative notes, and resident PGY level was determined by the date of TKA and its duration since the resident entered the program and using the standard resident academic calendar (July – June). Multivariable regression was used to assess PCS scores, operative time, length of stay, and facility discharge in patients whose surgery was performed with and without intraoperative resident participation, accounting for PGY training level and number of residents. We defined the

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Each author certifies that his institution approved the human protocol for this investigation and that all investigations were conducted in conformity with ethical principles of research.
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MCID PCS score improvement as 5 points on a 100-point scale. Adjusting variables included surgeon, academic year, age, sex, race–ethnicity, Charlson Comorbidity Index, preoperative PCS, and patient-reported mental function, BMI, tobacco use, alcohol use, and postoperative PCS time for the PCS models. We had postoperative PCS for 1417 (87%) surgeries.

Results Compared with attending-only TKAs (5% of procedures), no postgraduate year or number of residents was associated with either postoperative PCS or MCID PCS improvement (PCS: PGY-1 = -0.98, 95% CI, -6.14 to 4.17, p = 0.708; PGY-2 = -0.26, 95% CI, -2.01to 1.49, p = 0.768; PGY-3 = -0.32, 95% CI, -2.16 to 1.51, p = 0.730; PGY-4 = -0.28, 95% CI, -1.99 to 1.43, p = 0.746; PGY-5 = -0.47, 95% CI, -2.13 to 1.18, p = 0.575; two residents = 0.28, 95% CI, -1.05 to 1.62, p = 0.677) (MCID PCS: PGY-1 = odds ratio [OR], 0.30, 95% CI, 0.07–1.30, p = 0.108; PGY-2 = OR, 0.86, 95% CI, 0.46–1.62, p = 0.641; PGY-3 = OR, 0.97, 95% CI, 0.49–1.89, p = 0.921; PGY-4 = OR, 0.73, 95% CI, 0.39–1.36, p = 0.325; PGY-5 = OR, 0.71, 95% CI, 0.39–1.29, p = 0.259; two residents = OR, 1.23, 95% CI, 0.80–1.89, p = 0.337). Longer operative times were associated with all PGY levels except for PGY-5 (attending surgeon only [reference] = 85.60 minutes, SD, 14.5 minutes; PGY-1 = 100. 13 minutes, SD, 21.22 minutes, +8.44 minutes, p = 0.015; PGY-2 = 103.40 minutes, SD, 23.01 minutes, +11.63 minutes, p < 0.001; PGY-3 = 97.82 minutes, SD, 18.24 minutes, +9.68 minutes, p < 0.001; PGY-4 = 96.39 minutes, SD, 18.94 minutes, +4.19 minutes, p = 0.011; PGY-5 = 88.91 minutes, SD, 19.81 minutes, -0.29 minutes, p = 0.853) or the presence of multiple residents (+4.39 minutes, p = 0.024). There were no associations with length of stay (PGY-1 = +0.04 days, 95% CI, -0.63 to 0.71 days, p = 0.912; PGY-2 = -0.08 days, 95% CI, -0.48 to 0.33 days, p = 0.711; PGY-3 = -0.29 days, 95% CI, -0.66 to 0.09 days, p = 0.131; PGY-4 = -0.30 days, 95% CI, -0.69 to 0.08 days, p = 0.120; PGY-5 = -0.28 days, 95% CI, -0.66 to 0.10 days, p = 0.145; two residents = -0.12 days, 95% CI, -0.29 to 0.06 days, p = 0.196) or facility discharge (PGY-1 = OR, 1.03, 95% CI, 0.26–4.08, p = 0.970; PGY-2 = OR, 0.61, 95% CI, 0.31–1.20, p = 0.154; PGY-3 = OR, 0.98, 95% CI, 0.48–2.02, p = 0.964; PGY-4 = OR, 0.83, 95% CI, 0.43–1.57, p = 0.599; PGY-5 = OR, 0.7, 95% CI, 0.41–1.40, p = 0.372; two residents = OR, 0.93, 95% CI, 0.56–1.54, p = 0.766) for any PGY or number of residents.

Conclusions Our findings should help assure patients, residents, physicians, insurers, and hospital administrators that resident participation, after adjusting for numerous patient and clinical factors, does not have any association with key medical and financial metrics, including postoperative PCS, MCID PCS, length of stay, and facility discharge. Future research in this field should focus on whether residents affect knee-specific patient-reported outcomes such as the Knee Injury and Osteoarthritis Score and additional orthopaedic procedures, and determine how resident medical education can be further enhanced without compromising patient care and safety.

Level of Evidence Level III, therapeutic study.

Introduction

Orthopaedic surgery residency programs have the primary responsibility of providing safe, efficacious patient care while encouraging operative procedural training of residents. Orthopaedic surgical residents in the United States aim to generally increase individual competence and independence as their training progresses. Because teaching hospitals, which perform approximately half of all surgeries and a third of all orthopaedic surgeries, strive to balance this educational mission while providing the highest quality patient care, it is important that robust research evaluates the relationship between resident participation and postgraduate year (PGY) training level and any adverse effect of this participation on quality of surgical care [31]. Studies disagree regarding whether resident participation in orthopaedic surgery increases the risk of harm to patients or has any association with patient improvements in pain and function [11, 18-20, 26, 30, 31]. Previous evidence suggested that resident participation in spinal fusion surgeries was associated with increased complications, length of stay (LOS), operative time, and blood transfusion [18-20, 30]. Conversely, a report using the National Surgical Quality Improvement Program (NSQIP) database found a decrease in perioperative complications and mortality in all orthopaedic procedures with resident assistance [11]. TKA and THA may be particularly important to evaluate, because a large-series study showed greater odds for 30-day postoperative complications with resident participation, whereas a higher risk for complications was not found after other orthopaedic procedures [31]. These findings indicated that resident seniority may be associated with LOS, operative time, and postoperative morbidity [26]. However, only short-term complications were evaluated in these studies.

Patient-reported outcomes (PROs) assess patient health status directly from the patient's perspective [36]. The use of PROs dates to the 1980s and has been increasingly reported in research [12, 35]. Traditional hospital-based clinical metrics such as mortality and hospital readmission rates reveal low prevalence measures and may not offer sufficient sensitivity to discern variations for low-risk procedures such as TKA [5]. Integration of these standardized surveys in clinical practice provides a mechanism for monitoring longitudinal changes in symptom severity and patient function, aiding the evaluation of surgical findings [3]. Currently, there is no evidence of which we are aware regarding associations between intraoperative orthopaedic resident participation and postoperative PRO physical function in TKA.

The purpose of our study was to examine the effects of resident participation and their training level on postoperative outcomes among patients undergoing unilateral TKA, including patient-reported physical function. Specifically, we asked: (1) Are resident participation, PGY training level, and number of residents associated with absolute postoperative Patient-Reported Outcomes Measurement Information System (PROMIS®-10) global physical function score (PCS), and achieving minimum clinically important difference (MCID) PCS improvement, after TKA? (2) Are resident participation, PGY, and number of residents associated with increased TKA operative time? (3) Are resident participation, PGY, and number of residents associated with increased TKA LOS? (4) Are resident participation, PGY, and number of residents associated with higher odds of patients being discharged to another inpatient facility, rather than to their home (facility discharge)?

Patients and Methods

We performed an institutional review board-approved study of all patients who underwent unilateral primary TKA from April 2011 through July 2016 at our tertiary academic rural institution in the northeastern United States. Our study received expedited approval with waived consent. All data for this retrospective study were obtained from our longitudinally maintained institutional orthopaedic data repository.

A total of 1626 unilateral primary TKAs were available for analysis from April 2011 through July 2016 (Table 1).

We excluded bilateral TKAs (n = 531) because our database did not record the extent of resident participation for each knee and repeat primary TKA on the contralateral knee (n = 151). Because the PCS postoperative model requires postoperative PCS and the MCID PCS change model requires pre- and postoperative PCS, those models include 1417 (87%) (Table 2) and 1333 (82%) (Table 3) TKAs, respectively. Among the postoperative PCS scores, 43% were captured at approximately 1-year postoperative (defined as 10–14 months, or 300–420 days), 19% after 1 year (421+ days), 27% between 46 to 299 days postoperative (between our department's standard 1-month and 1-year followups), and 12% at the patient's first followup (between 1 and 45 days postoperative) (Table 1). This period is included as an adjusting variable in the PCS models (Tables 2 and 3). There were some preoperative differences between patients who did or did not have

Table 1. Variable counts

Variable	Count (n = 1626)	Percent
Experience of most-senior resident in operating room (reference = attending only)	89	5
PGY-5	615	38
PGY-4	422	26
PGY-3	201	12
PGY-2	291	18
PGY-1	8	< 1
Number of residents in the operating room (reference = 1)	1396	86
2*	141	9
0	89	5
Race (reference = non-Hispanic white)	1591	98
Ethnic minority	35	2
Surgeon (reference = Surgeon 1)	418	26
2	307	19
3	239	15
4	226	14
5	163	10
6	90	6
7	87	5
8	48	3
9	38	2
10	10	1
Age group (years; reference = < 55)	235	14
55-59	238	15
60-64	288	18
65-69	329	20
70-74	237	15
75-79	167	10
80+	131	8
Sex (reference = male)	705	43
Female	921	57
Preoperative alcohol use (reference = no)	610	38
Yes	949	58
Preoperative tobacco use (reference = never)	749	46
Quit	735	45
Yes	120	7
Charlson score (reference = 0)	931	57
1	338	21
2+	357	22
Academic year (reference = April–June 2011)	52	3
July 2011–June 2012	344	22

Table 1. continued

Variable	Count (n = 1626)	Percent
July 2012–June 2013	331	20
July 2013–June 2014	337	21
July 2014–June 2015	271	17
July 2015–June 2016	282	17
July 2016	9	1
BMI preoperative mean (kg/m^2; SD, range), n = 1487 (91%)	32.1 (7.3, 17.8-70.4)	
Normal, < 25	203	12
Overweight, 25-29.99	468	29
Obese, 30-34.99	356	22
Severely obese, 35-39.99	265	16
Morbidly obese, 40+	195	12
Length of surgery (minutes), mean (SD, range)	94.4 (20.6, 52–276)	
Length of stay (days), mean (SD, range)	2.8 (1.3, 1-21)	
1	154	9
2	582	36
3	611	38
4	173	11
5	58	4
6	24	1
7	9	1
8	7	0
9	2	0
11	1	0
12	1	0
13	2	0
14	1	0
21	1	0
Discharge disposition (reference = home)	1223	75
Facility	403	25
PCS preoperative mean (SD, range), n = 1521 (94%)†	40.3 (6.3, 23.5-67.7)	
PCS preoperative group (reference = 50+)	133	9
40-49.99	532	35
30-39.99	791	52
20-29.99	65	4
MCS preoperative mean (SD, range), n = 1502 (92%)	50.6 (8.7, 21.2-70.2)	
MCS preoperative group (reference = 60+)	198	13
50-59.99	634	42
40-49.99	497	33
< 40	173	12

Table 1. continued

Variable	Count (n = 1626)	Percent
PCS postoperative mean (SD, range), n = 1417 (87%)	46.4 (8.5, 19.9-67.7)	
PCS postoperative group (reference = 50+)	515	36
40-49.99	508	36
30-39.99	367	26
< 30	27	2
PCS change (SD, range), n = 1334 (82%)	5.9 (7.5, -21.1 to 32.2)	
PCS clinically significant improvement, > 5 score increase (reference = no)	607	46
Yes	727	55
Latest PCS postoperative period (reference = 1–45 days postoperative), n = 1417 (87%)‡	163	12
46–299 days postoperative	382	27
300–420 days postoperative (1 year)	606	43
421+ days postoperative	266	19

Percentages may not add to 100 and counts to 1626 owing to missingness or rounding.
*there were two surgeries in which three residents were in the operating room and three in which a second attending was in the operating room.
†Veterans RAND 12-item health survey (VR-12) and Patient-Reported Outcome Measurement Information System-Global Health (PROMIS®-10) physical component scores (PCS) were collected; of the 1626 surgeries, the preoperative collections were 87% for VR-12, 62% for PROMIS®-10, and 95% for at least one of them; in the postoperative periods, the capture rate was 74% for VR-12, 80% for PROMIS®-10, and 87% for at least one of them; among patients with completed patient-reported outcomes pre- and postoperatively, capture rates were 71% for VR-12, 56% for PROMIS®-10, and 82% for at least one of them; VR-12 scores were converted to PROMIS®-10 scores (13); PROMIS®-10 scores "take priority" when VR-12 and PROMIS®-10 scores are available.
‡if multiple postoperative periods are captured, the "priority" is: 300–420 days (1 year), 421+ days, 300–420 days, 46–299 days, 0–45 days; PGY = postgraduate year; MCS = mental component score.

a postoperative PCS, including surgeon ($p = 0.009$); alcohol use (62% of patients with postoperative PCS drank alcohol versus 50% of patients with no postoperative PCS, $p = 0.003$); Charlson Comorbidity Index (46% versus 21% with at least one comorbidity, $p < 0.001$); resident year ($p < 0.001$); PCS (40.6 [SD, 6.3] versus 38.2 [SD, 5.6], $p < 0.001$); and mental component score (MCS) (50.9 [SD, 8.7] versus 48.3 [SD, 8.7], $p < 0.001$) (data not shown). All

Table 2. Multivariable linear regression model for associations with postoperative PCS

Variable	Postoperative PCS	95% CI	p value
Senior resident (reference = attending only)			
PGY-5	-0.47	-2.13 to 1.18	0.575
PGY-4	-0.28	-1.99 to 1.43	0.746
PGY-3	-0.32	-2.16 to 1.51	0.730
PGY-2	-0.26	-2.01 to 1.49	0.768
PGY-1	-0.98	-6.14 to 4.17	0.708
Number of residents in the operating room (reference = 1)			
2	0.28	-1.05 to 1.62	0.677
Surgeon (reference = Surgeon 1)			
2	-0.64	-1.84 to 0.56	0.294
3	-0.70	-2.05 to 0.64	0.305
4	-0.57	-2.00 to 0.86	0.433
5	0.13	-1.35 to 1.61	0.865
6	-1.51	-3.32 to 0.30	0.103
7	-0.18	-1.93 to 1.56	0.837
8	-2.08	-4.58 to 0.42	0.103
9	1.48	-1.09 to 4.05	0.259
10	0.06	-5.16 to 5.29	0.981
Academic year (reference = April–June 2011)			
July 2011–June 2012	2.68	0.51–4.85	0.016*
July 2012–June 2013	3.61	1.41–5.82	0.001*
July 2013–June 2014	4.19	1.97–6.40	< 0.001*
July 2014–June 2015	3.25	0.98–5.52	0.005*
July 2015–June 2016	4.45	1.89–7.01	0.001*
July 2016	3.65	-2.38 to 9.68	0.236
Age group (years; reference = < 55)			
55–59	1.04	-0.42 to 2.50	0.162
60–64	0.93	-0.42 to 2.28	0.177
65–69	0.90	-0.46 to 2.23	0.195
70–74	1.17	-0.26 to 2.60	0.109
75–79	1.20	-0.41 to 2.80	0.145
80+	0.16	-1.68 to 2.00	0.863
Sex (reference = male)			
Female	0.68	-0.08 to 1.44	0.081
Race–ethnicity (reference = non-Hispanic white)			
Ethnic minority	-3.14	-6.34 to 0.05	0.054
Charlson score (reference = 0)			
1	-1.72	-2.68 to -0.77	< 0.001*
2+	-1.88	-2.82 to -0.95	< 0.001*
PCS preoperative (reference = 50+)			
40-49.99	-2.28	-3.66 to -0.90	0.001*
30-39.99	-5.50	-6.99 to -4.00	< 0.001*
20-29.99	-7.49	-10.37 to -4.60	< 0.001*
MCS preoperative (reference = 60+)			
50-59.99	-2.17	-3.40 to -0.95	0.001*
40-49.99	-4.99	-6.38 to -3.59	< 0.001*

Table 2. continued

Variable	Postoperative PCS	95% CI	p value
< 40	-8.52	-10.32 to -6.72	< 0.001*
Latest PCS postoperative period (reference = 0–45 days postoperative)			
46–299 days postoperative	3.36	2.19-4.42	< 0.001*
300–420 days postoperative (1 year)	5.91	4.64-7.18	< 0.001*
421+ days postoperative	4.99	3.55-6.43	< 0.001*
BMI preoperative (kg/m^2; reference = normal, < 25)			
Overweight, 25-29.99	0.27	-0.95 to 1.49	0.668
Obese, 30-34.99	-0.41	-1.69 to 0.88	0.535
Severely obese, 35-39.99	-1.12	-2.52 to 0.28	0.116
Morbidly obese, 40+	-2.26	-3.72 to -0.80	0.002*
Tobacco use (reference = never)			
Quit	-0.16	-0.93 to 0.62	0.691
Yes	-1.62	-3.20 to -0.04	0.045*
Alcohol use (reference = no)			
Yes	0.40	-0.41 to 1.20	0.336

*p < 0.05; positive is a higher score than the reference; a score of 1.00 is a higher adjusted score (higher physical function) compared with the reference; because postoperative PCS is required, this model has 1417 surgeries (87%); PCS = physical component score; PGY = postgraduate year; MCS = mental component score.

of these factors were adjusting variables in our multivariable statistical models. There were no differences by postoperative PCS capture rates by resident PGY, number of residents, race, age, sex, tobacco use, and BMI (data not shown).

Other outcomes had minor exclusions. Two (0.1%) patients are not included in the operative time model owing to incorrect capture of recorded times in the electronic medical record (Table 4). All patients are included in the LOS model (Table 5). Ten (0.6%) patients were not included in the facility discharge because their surgeon, who had a low-volume of TKAs, did not have any variation in the model (all 10 were discharged to home) and therefore could not be calculated (Table 6).

Residents present during the TKA were identified in individual chart reviews and their PGY level was based on the date of surgery compared with their entry in the resident program (Table 1). TKAs were performed by 10 orthopaedic attending surgeons with or without the assistance of residents. Orthopaedic surgery residents present during surgery represent all levels of training from PGY-1 to -5. In cases in which multiple residents were present (n = 141; 9%), the more-senior resident was assumed to be the first assistant. During the study period, there were 37 orthopaedic surgery residents at our institution. Intraoperative complications were documented in four cases (three tibia fractures and one medial collateral ligament injury), but the intraoperative complication rate was too low to discern any relationship to year of training or resident participation and these were not explored further.

All model variables were recorded preoperatively and obtained from our longitudinally maintained institutional repository (Table 1). Our primary variables were the PGY level of the senior resident (with a reference category of "attending surgeon only") and the number of residents present in the operating room. Adjusting factors included age [23, 28, 38], sex [23, 28, 38], race–ethnicity (non-Hispanic white versus ethnic minority) [13, 14], surgeon [28], alcohol use [21], tobacco use [21, 34], Charlson Comorbidity score [28], academic year (July-June), clinically recorded BMI [8, 28], PCS [28, 32, 33], and MCS [16]. Our models included postoperative PCS and a conservative MCID PCS improvement of 5 points or greater [4, 15, 33], operative time, LOS, and facility discharge. We used the established, standardized PROMIS-10 and Veterans RAND 12-item health survey to determine PCS and MCS with time. We collected both, sometimes concurrently, during the study period, prioritizing the PROMIS-10. If PROMIS-10 scores were not available, the Veterans RAND-12 PCS and MCS were converted to the PROMIS-10 scale using a recent validated crosswalk [29]. Operative time was defined as the elapsed minutes from the initiation of skin incision to completed wound closure. LOS was captured in days. Discharge disposition was dichotomized in home versus facility [28]. There were no changes in pre- and postoperative protocols during the study period.

There were no differences in patient demographics by resident participation. Residents assisted in 95% of cases, including 9% of total cases in which at least two residents were involved. Although it was impossible to quantify the exact percentage of resident involvement in any given case,

Table 3. Multivariable logistic regression model for associations with clinically significant PCS improvement, defined as 5 points

Variable	Odds ratio	95% CI	p Value
Senior resident (reference = attending only)			
PGY-5	0.71	0.39–1.29	0.259
PGY-4	0.73	0.39–1.36	0.325
PGY-3	0.97	0.49–1.89	0.921
PGY-2	0.86	0.46–1.62	0.641
PGY-1	0.30	0.07–1.30	0.108
Number of residents in the operating room (reference = 1)			
2	1.23	0.80–1.89	0.337
Surgeon (reference = Surgeon 1)			
2	0.69	0.46–1.01	0.058
3	0.74	0.48–1.14	0.173
4	0.75	0.48–1.17	0.199
5	0.92	0.57–1.47	0.724
6	0.37	0.19–0.74	0.005*
7	0.81	0.42–1.56	0.526
8	0.49	0.21–1.15	0.100
9	0.85	0.34–2.09	0.717
10	2.21	0.66–7.36	0.196
Academic year (reference = April–June 2011)			
July 2011–June 2012	2.18	0.995–4.76	0.051
July 2012–June 2013	2.80	1.26–6.20	0.011*
July 2013–June 2014	2.64	1.19–5.87	0.017*
July 2014–June 2015	2.20	0.97–5.00	0.059
July 2015–June 2016	3.01	1.21–7.48	0.018*
July 2016	NA	NA	NA
Age group (years; reference = < 55)			
55–59	1.47	0.94–2.29	0.089
60–64	1.63	1.07–2.50	0.024*
65–69	1.69	1.11–2.58	0.014*
70–74	1.83	1.15–2.92	0.011*
75–79	2.28	1.35–3.83	0.002*
80+	1.16	0.67–2.02	0.597
Sex (reference = male)			
Female	1.22	0.95–1.56	0.115
Race–ethnicity (reference = non-Hispanic white)			
Ethnic minority	0.45	0.21–1.001	0.050
Charlson score (reference = 0)			
1	0.64	0.47–0.86	0.004*
2+	0.73	0.54–0.996	0.047*
PCS preoperative (reference = 50+)			
40-49.99	5.18	3.21–8.37	< 0.001*
30-39.99	10.83	6.34–18.49	< 0.001*
20-29.99	35.98	14.49–89.37	< 0.001*
MCS preoperative (reference = 60+)			
50-59.99	0.75	0.50–1.13	0.172
40-49.99	0.37	0.23–0.60	< 0.001*
< 40	0.21	0.12–0.38	< 0.001*

Table 3. continued

Variable	Odds ratio	95% CI	p Value
Latest PCS postoperative period (reference = 0–45 days postoperative)			
46–299 days postoperative	2.60	1.68–4.02	< 0.001*
300–420 days postoperative (1 year)	4.23	2.67–6.71	< 0.001*
421+ days postoperative	3.21	1.93–5.33	< 0.001*
BMI preoperative (kg/m^2; reference = normal, < 25)			
Overweight, 25-29.99	1.48	0.997–2.21	0.052
Obese, 30-34.99	1.22	0.80–1.86	0.349
Severely obese, 35-39.99	0.99	0.63–1.54	0.958
Morbidly obese, 40+	0.85	0.52–1.39	0.507
Tobacco use (reference = never)			
Quit	0.90	0.70–1.16	0.420
Yes	0.98	0.61–1.57	0.926
Alcohol use (reference = no)			
Yes	1.00	0.77–1.29	0.998

*p < 0.05; an odds ratio > 1 has higher odds of significant improvement compared with reference; contains 1333 (82%) because preoperative and postoperative PCS are required; PCS = physical component score; PGY = postgraduate year; MCS = mental component score; NA = none available.

we polled all of our attending surgeons performing TKAs during the study period (April 2011 – July 2016) to gain a sense of graduated resident involvement as they progressed through residency (Table 7). PGY-5 residents had the most-frequent senior training level present in the operating room (38%) compared with PGY-4 (26%), PGY-3 (12%), PGY-2 (18%), and PGY-1 (< 1%). The mean age for our patient sample was 65.5 years (SD, 10.1 years), with a mean preoperative PCS of 40.3 (SD, 6.3) and MCS of 50.6 (SD, 8.7). Fifty-seven percent of patients were female and 98% were classified as white, which reflects the local older population [25]. Although there was a mean MCID-achieved PCS improvement (5.89 score improvement, SD, 7.50), 46% did not achieve MCID PCS improvement of 5 points or greater (Table 1) and 16% had lower PCS scores postoperatively (data not shown).

We collected additional postoperative data that are not reflected in the analytic models (Table 1). The PCS change score was measured as the latest available postoperative recorded PCS subtracted by the latest preoperative score; a positive change score indicates PCS improvement. The period captured by the postoperative PCS was included in the PCS change models. We also documented any additional all-cause same-knee surgery ("reoperations") within 90 days of the primary TKA.

Statistical Analysis

We used multivariable regression techniques for all analytic models and robust standard errors to account for the observational study. Linear regression was used for the postoperative PCS, length of surgery, and LOS models, whereas dichotomous logistic regression was used for determining the MCID PCS improvement and discharge status. Because all surgeries were done at one tertiary academic institution, and all second primary TKAs were excluded, there were no repeat patients and no clustering. Statistical significance was set at a probability less than 0.05. All analyses used Stata 12 MP™ (StataCorp, College Station, TX, USA).

Results

After accounting for other factors like BMI, surgeon, and preoperative PCS, resident PGY level and number of residents were not associated with postoperative PCS (Table 2). Compared with attending-only TKAs, no PGY had different postoperative PCS (PGY-5: -0.47 points, 95% CI, -2.13 to 1.18, p = 0.575; PGY-4: -0.28 points, 95% CI, -1.99 to 1.43, p = 0.746; PGY-3: -0.32 points, 95% CI, -2.16 to 1.51, p = 0.730; PGY-2: -0.26 points, 95% CI, -2.01 to 1.49, p = 0.768; PGY-1: -0.98 points, 95% CI, -6.14 to 4.17, p = 0.708). No differences were found for postoperative PCS between having two residents compared with one (0.28 points, 95% CI, -1.05 to 1.62; p = 0.677).

There also were no associations between resident PGY level and number of residents and the likelihood of achieving an equal or greater improvement than the MCID for PCS improvement (Table 3). Compared with attending-

Table 4. Multivariable linear regression model for associations with longer length of surgery (in minutes)

Variable	Additional minutes	95% CI	p value
Senior resident (reference = attending only)			
PGY-5	-0.29	-3.41 to 2.82	0.853
PGY-4	4.19	0.97–7.41	0.011*
PGY-3	9.68	6.03–13.32	< 0.001*
PGY-2	11.63	7.85–15.40	< 0.001*
PGY-1	8.44	1.65–15.23	0.015*
Number residents in the operating room (reference = 1)			
2	4.39	0.58–8.19	0.024*
Surgeon (reference = Surgeon 1)			
2	-2.70	-5.87 to 0.47	0.095
3	22.43	18.97–25.89	< 0.001*
4	13.36	6.96–19.77	< 0.001*
5	-6.39	-9.40 to -3.38	< 0.001*
6	24.93	20.64–29.22	< 0.001*
7	10.84	6.36–15.33	< 0.001*
8	3.52	-2.21 to 9.25	0.229
9	21.44	15.75–27.12	< 0.001*
10	20.27	12.49–28.05	< 0.001*
Academic year (reference = April–June 2011)			
July 2011–June 2012	-16.14	-42.29 to 10.01	0.226
July 2012–June 2013	-17.62	-43.79 to 8.55	0.187
July 2013–June 2014	-18.23	-43.44 to 6.98	0.156
July 2014–June 2015	-12.73	-37.37 to 11.91	0.311
July 2015–June 2016	-16.78	-41.44 to 7.89	0.182
July 2016	-13.80	-38.55 to 10.94	0.274
Age group (years; reference = < 55)			
55–59	-0.51	-6.07 to 5.05	0.858
60–64	-2.20	-5.17 to 0.77	0.147
65–69	-1.49	-4.61 to 1.63	0.348
70–74	-5.42	-8.30 to -2.53	< 0.001*
75–79	-7.03	-10.71 to -3.35	< 0.001*
80+	-8.14	-11.63 to -4.65	< 0.001*
Sex (reference = male)			
Female	-7.75	-10.72 to -4.79	< 0.001*
Race–ethnicity (reference = non-Hispanic white)			
Ethnic minority	-1.48	-7.69 to 4.73	0.641
Charlson score (reference = 0)			
1	-1.11	-3.34 to 1.13	0.331
2+	-1.37	-3.60 to 0.85	0.226
PCS preoperative (reference = 50+)			
40-49.99	-0.72	-4.21 to 2.78	0.689
30-39.99	-0.68	-4.36 to 3.01	0.719
20-29.99	-0.79	-6.11 to 4.53	0.771
MCS preoperative (reference = 60+)			
50-59.99	-1.67	-4.63 to 1.29	0.269
40-49.99	-0.42	-3.67 to 2.83	0.799

Table 4. continued

Variable	Additional minutes	95% CI	p value
< 40	1.93	-2.27 to 6.12	0.367
BMI preoperative (kg/m^2; reference = normal, < 25)			
Overweight, 25-29.99	0.48	-2.99 to 3.95	0.787
Obese, 30-34.99	0.01	-2.93 to 2.95	0.997
Severely obese, 35-39.99	0.34	-2.82 to 3.50	0.832
Morbidly obese, 40+	6.72	1.81-11.62	0.007*
Tobacco use (reference = never)			
Quit	-0.75	-3.23 to 1.73	0.553
Yes	-4.38	-8.46 to -0.30	0.035*
Alcohol use (reference = no)			
Yes	-1.89	-4.64 to 0.86	0.178

*p < 0.05; an outcome of 1.00 is 1 minute longer compared with the reference; two surgeries did not have times recorded correctly and were not included, so 1624 surgeries (99.9%) are in this model; PGY = postgraduate year; PCS = physical component score; MCS = mental component score.

only TKAs, no PGY had different postoperative MCID PCS improvement (PGY-5: odds ratio [OR] of MCID improvement, 0.71, 95% CI, 0.39–1.29, p = 0.259; PGY-4: OR, 0.73, 95% CI, 0.39–1.36, p = 0.325; PGY-3: OR, 0.97, 95% CI, 0.49–1.89, p = 0.921; PGY-2: OR, 0.86, 95% CI, 0.46–1.62, p = 0.641; PGY-1: OR, 0.30, 95% CI, 0.07–1.30, p = 0.108). Additionally, no difference was found by having multiple residents in the operating room compared with one (OR, 1.23, 95% CI, 0.80–1.89, p = 0.337).

All PGY training levels except for the PGY-5 group were associated with longer operative times compared with mean attending-only surgery of 86 minutes (SD, 15 minutes) (PGY-1 = +8.44 minutes, 95% CI, 1.65–15.23 minutes, p = 0.015; PGY-2 = +11.63 minutes, 95% CI, 7.85–15.40, p < 0.001; PGY-3 = +9.68 minutes, 95% CI, 6.03–13.32, p < 0.001; PGY-4 = +4.19 minutes, 95% CI, 0.97–7.41, p = 0.011; PGY-5 = -0.29 minutes, 95% CI, -3.41 to 2.82, p = 0.853), as was participation of more than one resident during surgery (+4.39 minutes, 95% CI, 0.58–8.19, p = 0.024, compared with one resident) (Table 4). However, there was greater variation in operative time among individual attending orthopaedic surgeons (range, -6.39 to 24.93 minutes, compared with Surgeon 1). Older patients and female sex were associated with shorter operative times.

No difference in hospital LOS was found between different levels of resident training or the presence of two residents (Table 5) (PGY-5: -0.28 days, 95% CI, -0.66 to 0.10 days, p = 0.145; PGY-4: -0.30, 95% CI, -0.69 to 0.08, p = 0.120; PGY-3: -0.29, 95% CI, -0.66 to 0.09, p = 0.131; PGY-2: -0.08, 95% CI -0.48 to 0.33, p = 0.711; PGY-1: 0.04, 95% CI, -0.63 to 0.71, p = 0.912). Older patients and female patients were associated with longer LOS as were higher Charlson Comorbidity Index and BMI and lower preoperative PCS and MCS.

Similarly, no difference in odds of facility discharge, defined as discharge to anywhere but the patient's home [28], was found among different levels of resident training or the presence of two residents (Table 6) (PGY-5: OR, 0.75 of facility discharge compared with attending-only TKA, 95% CI, 0.41–1.40, p = 0.372; PGY-4: OR, 0.83, 95% CI, 0.43–1.57, p = 0.599; PGY-3: OR, 0.98, 95% CI, 0.48–2.02, p = 0.964; PGY-2: OR, 0.61, 95% CI, 0.31–1.20, p = 0.154; PGY-1: OR, 1.03, 95% CI, 0.26–4.08, p = 0.970). In an adjusted multivariable model, older patients, female patients, higher Charlson Comorbidity Index, higher BMI, lower PCS, and lower MCS were all associated with facility discharge.

Using the data repository and patient charts, we identified 11 known cases of a patient returned to the operating room for a knee-specific additional surgery within 90 days of the primary unilateral TKA (0.7%). These 11 cases included four infections, two cases of hemarthrosis, one case of avascular necrosis, a wound dehiscence with likely patellar tendon injury, dehiscence of the incision, revision to correct patellar subluxation, and revision for instability and clunk. There was no discernible pattern for individual residents or PGY level and we did not have the counts to investigate reoperations further. In the attending-only group, there were no cases of intraoperative complications or additional 90-day knee-specific surgery.

Discussion

Although approximately one-third of all orthopaedic procedures in the United States are performed at teaching hospitals, the effect of resident participation and their level of training on patient care for TKA outcomes is currently

Table 5. Multivariable linear regression models for associations with length of stay (in days)

Variable	Days (coefficient)	95% CI	p Value
Senior resident (reference = attending only)			
PGY-5	-0.28	-0.66 to 0.10	0.145
PGY-4	-0.30	-0.69 to 0.08	0.120
PGY-3	-0.29	-0.66 to 0.09	0.131
PGY-2	-0.08	-0.48 to 0.33	0.711
PGY-1	0.04	-0.63 to 0.71	0.912
Number of residents in the operating room (reference = 1)			
2	-0.12	-0.29 to 0.06	0.196
Surgeon (reference = Surgeon 1)			
2	0.06	-0.16 to 0.29	0.582
3	-0.09	-0.32 to 0.14	0.419
4	0.27	0.04-0.49	0.020*
5	-0.01	-0.29 to 0.27	0.945
6	0.05	-0.21 to 0.30	0.720
7	-0.47	-0.78 to -0.16	0.003*
8	0.18	-0.15 to 0.51	0.275
9	-0.14	-0.54 to 0.26	0.486
10	-0.72	-1.28 to -0.16	0.012*
Academic year (reference = April–June 2011)			
July 2011–June 2012	-0.45	-1.05 to 0.14	0.133
July 2012–June 2013	-0.58	-1.18 to 0.02	0.058
July 2013–June 2014	-0.50	-1.11 to 0.11	0.109
July 2014–June 2015	-0.75	-1.38 to -0.12	0.019*
July 2015–June 2016	-1.32	-1.94 to -0.70	< 0.001*
July 2016	-1.64	-2.55 to -0.73	< 0.001*
Age group (years; reference = < 55)			
55–59	-0.02	-0.22 to 0.19	0.866
60–64	0.07	-0.15 to 0.29	0.520
65–69	0.15	-0.04 to 0.34	0.113
70–74	0.24	0.04-0.44	0.020*
75–79	0.43	0.21-0.66	< 0.001*
80+	0.77	0.42-1.12	< 0.001*
Sex (reference = male)			
Female	0.15	0.03-0.27	0.012*
Race–ethnicity (reference = non-Hispanic white)			
Ethnic minority	0.29	-0.08 to 0.66	0.121
Charlson score (reference = 0)			
1	0.12	-0.02 to 0.25	0.095
2+	0.36	0.18-0.53	< 0.001*
PCS preoperative (reference = 50+)			
40-49.99	0.09	-0.08 to 0.26	0.284
30-39.99	0.31	0.12-0.50	0.002*
20-29.99	0.53	0.11-0.95	0.014*
MCS preoperative (reference = 60+)			
50-59.99	0.16	0.02-0.30	0.030*

Table 5. continued

Variable	Days (coefficient)	95% CI	p Value
40-49.99	0.43	0.22-0.63	< 0.001*
< 40	0.68	0.39-0.96	< 0.001*
BMI preoperative (kg/m^2; reference = normal, < 25)			
Overweight, 25-29.99	0.07	-0.07 to 0.22	0.324
Obese, 30-34.99	0.19	-0.02 to 0.40	0.076
Severely obese, 35-39.99	0.21	0.01-0.41	0.038*
Morbidly obese, 40+	0.51	0.26-0.77	< 0.001*
Tobacco use (reference = never)			
Quit	0.001	-0.12 to 0.12	0.983
Yes	0.05	-0.18 to 0.27	0.689
Alcohol use (reference = no)			
Yes	-0.11	-0.25 to 0.02	0.094

*p < 0.05; value of 1.00 indicates one additional day compared with the reference; PGY = postgraduate year; PCS = physical component score; MCS = mental component score.

unclear [31]. We investigated this clinical question using PROs, operative time, LOS, and facility discharge as adjunctive measures to the current knowledge of clinical metrics and postoperative mortality data. Previous studies examining the intraoperative effects of residents have largely analyzed them as a homogenous unit without accounting for level of training [11, 18-20, 30, 31]. To further elucidate the role of resident participation in orthopaedic surgery, we examined the effects of resident experience according to PGY level. We examined the relationships between resident year of training and its effects on PROs, operative time, LOS, and discharge disposition in 1626 patients who underwent primary TKA. In this study, no associations were found between the training level of orthopaedic surgery residents and PROs assessed when compared with surgery without resident participation after applying numerous adjusting variables.

This study has numerous limitations. First, although we had complete or more than 99% inclusion rates for our operative time, LOS, and facility discharge outcomes, we had significant missingness for postoperative PCS in our unfunded pragmatic study. However, these capture rates are quite good in a pragmatic unfunded observational dataset and are similar to the funded American Joint Replacement, Function and Outcomes Research for Comparative Effectiveness in Total Joint Replacement, and California Joint Replacement registries [2, 15]. Those missing postoperative PCS differed in some ways. These differences might be explained in additional analyses outside the scope of the current study. For example, later years such as 2015 and 2016 may have lower followup rates because less time has passed, particularly for followups at least 1 year after the TKA (our analyses and followup dates go through July 2016); patients with higher Charlson Comorbidity Index scores may be more likely to have more clinical visits and thus more opportunities to record PCS; and some surgeons were in the dataset only during earlier years before capturing scores were more emphasized in our department. However, our data allow for inclusion of variables rarely available in previous studies, such as physical and mental function and clinic-measured BMI, and we statistically adjusted for the time in which postoperative PCS was captured. Second, it was not possible to determine the degree of involvement each resident had during surgery, and it may have varied by surgeon and other operating room and logistic factors that could not be measured or controlled. Additionally, we queried all 10 of the surgeons in our dataset regarding the degree of resident involvement they typically encouraged and found, as expected, graduated responsibility mirrored resident training level (Table 7). There also might be variations in resident skill level, confidence, and perceived difficulty and complexity of the case. Additionally, although we presented a large study cohort that drew data from a longitudinally maintained institutional registry, our patients were not randomly assigned and were from a single institution in a rural area. Although the geographic area does not have much racial and ethnic diversity, it presents much diversity for other socioeconomic status measures, including employment, education, income, and living alone status [15, 28]. Finally, although we attempted to adjust for patient differences using multivariable analyses, there were potentially other factors not captured by our database that may affect a pragmatic dataset. For example, we did not capture measures of case complexity beyond Charlson Comorbidity Index and BMI: measures such as Current Procedural Terminology codes and Relative Value Units may show additional complexities of the TKA that might affect resident participation [26].

Table 6. Multivariable logistic regression model for association with facility discharge

Variable	Odds ratio	95% CI	p Value
Senior resident (reference = attending only)			
PGY-5	0.75	0.41-1.40	0.372
PGY-4	0.83	0.43-1.57	0.599
PGY-3	0.98	0.48-2.02	0.964
PGY-2	0.61	0.31-1.20	0.154
PGY-1	1.03	0.26-4.08	0.970
Number of residents in the operating room (reference = 1)			
2	0.93	0.56-1.54	0.766
Surgeon (reference = Surgeon 1)			
2	1.03	0.65-1.62	0.896
3	1.26	0.76-2.08	0.368
4	1.76	1.04-2.98	0.034*
5	0.81	0.44-1.49	0.500
6	1.33	0.73-2.45	0.354
7	0.59	0.23-1.47	0.254
8	3.43	1.40-8.36	0.007*
9	1.18	0.31-4.44	0.807
10[†]	NA	NA	**NA**
Academic year (reference = April–June 2011)			
July 2011–June 2012	0.98	0.43-2.22	0.967
July 2012–June 2013	1.75	0.77-3.99	0.181
July 2013–June 2014	1.63	0.72-3.73	0.243
July 2014–June 2015	1.31	0.56-3.06	0.532
July 2015–June 2016	0.67	0.26-1.75	0.414
July 2016	0.57	0.10-3.41	0.540
Age group (years; reference = < 55)			
55–59	1.56	0.80-3.03	0.191
60–64	3.37	1.84-6.17	< 0.001*
65–69	5.30	2.88-9.73	< 0.001*
70–74	9.41	5.00-17.68	< 0.001*
75–79	18.42	9.47-35.80	< 0.001*
80+	29.07	14.71-57.44	< 0.001*
Sex (reference = male)			
Female	2.00	1.50-2.68	< 0.001*
Race–ethnicity (reference = non-Hispanic white)			
Ethnic minority	4.34	1.75-10.77	0.002*
Charlson score (reference = 0)			
1	1.35	0.95-1.91	0.099
2+	1.69	1.20-2.37	0.003*
PCS preoperative (reference = 50+)			
40-49.99	2.43	1.09-5.42	0.030*
30-39.99	4.61	2.01-10.59	< 0.001*
20-29.99	9.98	3.56-28.00	< 0.001*
MCS preoperative (reference = 60+)			
50-59.99	1.01	0.58-1.78	0.964
40-49.99	1.76	0.98-3.17	0.060

Table 6. continued

Variable	Odds ratio	95% CI	p Value
< 40	2.86	1.40-5.86	0.004*
BMI preoperative (kg/m^2; reference = normal, < 25)			
Overweight, 25-29.99	0.78	0.49-1.23	0.281
Obese, 30-34.99	0.99	0.62-1.59	0.965
Severely obese, 35-39.99	0.86	0.50-1.45	0.564
Morbidly obese, 40+	2.75	1.57-4.84	< 0.001*
Tobacco use (reference = never)			
Quit	0.98	0.74-1.31	0.910
Yes	1.22	0.67-2.20	0.515
Alcohol use (reference = no)			
Yes	0.60	0.46-0.80	< 0.001*

*p < 0.05; odds ratio greater than 1 indicates higher odds of facility discharge;
†Surgeon 10 was not included or calculated owing to lack of variation (no facility discharge), so 1616 (99%) surgeries were included; PGY = postgraduate year; PCS = physical component score; MCS = mental component score; NA = not available.

Intraoperative participation of orthopaedic surgery residents and their PGY level were not associated with changes in long-term physical function, as measured by either postoperative PCS change or MCID PCS improvement of 5 points or greater [4, 15, 33]. These findings may speak to the ability of a residency program to uphold its educational mission toward residents of all training levels without compromising patient care. To our knowledge, this is the first study to evaluate resident involvement with postoperative PRO PCS; other published studies investigated only short-term clinical measures of intraoperative resident participation, with varying conclusions [11, 18-20, 26, 30, 31, 39]. The goals of most patients undergoing TKA and other orthopaedic procedures are pain relief and improved physical function; therefore we propose PROs as an equally important metric in evaluating resident-related surgical measures. Interestingly, and in agreement with previous studies [15, 28], we showed that patients with the lowest preoperative PCS reported the greatest PCS improvement from TKA, whereas those with the lowest preoperative MCS reported the least clinical benefit. Moreover, in our patients undergoing TKA, the presence of multiple residents in the operating room was not associated with a difference in postoperative PROs. Although not a focus of our research questions, it is interesting that no attending-only TKA had an intraoperative complication or an additional 90-day knee-specific surgery in our unilateral TKA dataset. However, the small sample size of this group renders any comparisons challenging.

Among the models we examined, intraoperative resident participation had the greatest effect on operative duration. Consistent with previous reports on spinal surgery and minimally invasive THA, TKAs with resident participation were associated with longer operative times

Table 7. Attending surgeon's perspective regarding the percentage of primary TKAs performed by each resident level of training*

Surgeon	PGY-1	PGY-2	PGY-3	PGY-4	PGY-5	Mean
1	10	30	60	75	95	54
2	10	25	75	100	100	62
3	0	25	50	90	90	51
4	50	100	100	100	100	90
5	10	25	50	80	80	49
6	0	100	100	100	100	80
7	10	30	60	85	95	56
8	50	70	80	100	100	80
9	10	30	50	70	70	46
10	5	50	75	90	100	64
Mean	16	47	70	89	93	

*Includes all attending surgeons who performed TKAs at our institution during April 2011–July 2016.

[19, 20, 39]. In our resident sublevel analysis, compared with cases without a resident, all PGY levels (except PGY-5) and cases with multiple residents had longer operative times. Longer durations of surgery may be a result of resident inexperience and/or time devoted to teaching by the attending surgeon. From PGYs-2 to -5, there was a steady decline in the duration of surgery, which is supported by previous studies that increasing experience is linked to shorter operative times in orthopaedic procedures [6, 40]. Shorter lengths of surgery also may be related to a greater observational role and minimal hands-on operating experience for PGY-1 residents, whereas orthopaedic trainees participate in greater procedural roles starting at PGY-2 at our institution, as self-reported by our attending surgeons (Table 7). Longer operative times potentially can lead to an increased risk of infection, postoperative transfusion, readmissions, and reoperations in total joint arthroplasties, but the significance of the addition of a mean 11.6 minutes, after adjustment for other factors, in the longest group (PGY-2) is unclear (Table 4) [10,17, 25, 27]. However, individual attending surgeons were associated with much greater variations in operative duration compared with resident training level, even after adjustment for resident and patient characteristics. Our results are in contrast with the NSQIP primary knee and hip arthroplasty population reported by Pugely et al. [26], which showed that operative times were not affected by resident PGY level, despite having the same definition of operative time as we used, although their findings were inconsistent between different orthopaedic procedures. This topic has been explored more extensively in general surgery procedures with controversial results [1, 7, 9, 22, 24, 37].

As supported in other studies, we did not find any differences in LOS based on resident participation [7, 22, 24, 37]. However, Pugely et al. [26] reported increasing durations of hospital stay with higher PGY levels. Our study and data differ in numerous ways from their work. Pugely et al. [26] used the NSQIP dataset and had access to multicenter claims data; however, they did not capture several key variables that are available in our electronic medical records data, including Charlson Comorbidity Index, preoperative PCS and MCS, and individual surgeon. Additionally, we used individual PGYs while Pugely et al. dichotomized residents into "junior" and "senior" residents, and also included fellows [26]. Their findings also were inconsistent among different orthopaedic procedures assessed.

We also found no differences in odds of facility discharge between residents at various training levels participating in surgery. Other studies have noted no differences in similar 30-day outcomes [7, 22, 24, 37].

Although largely confirmatory, our study is notable for several reasons. We have postoperative PCS as an outcome and a preoperative adjusting variable, which, to the best of our knowledge, has not been used previously for resident participation study for TKAs, although it has become increasingly important to payers and the government. We provide contrasting evidence regarding any association resident participation may have on operative times, complications, and LOS [26]. Further study should attempt to have the counts of previous claims studies while including electronic medical records and PRO variables similar to our study.

Our findings should serve to assuage concerns from patients, surgeons, residents, and hospital administrators regarding resident participation in TKAs. Despite modestly longer operative times with junior residents, there were no differences in physical function, LOS, or discharge disposition among patients undergoing primary unilateral TKA with surgical participation of residents at any training level. The effect of intraoperative resident participation in orthopaedic surgeries on long-term patient function and additional surgeries would benefit from further investigation with the intention of improving resident education without compromising patient care.

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