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Do Aggregate Socioeconomic Status Factors Predict Outcomes for Total Knee Arthroplasty in a Rural Population?

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Abstract

Background—We sought to determine whether several pre-operative socioeconomic status (SES) variables meaningfully improve predictive models for primary total knee arthroplasty (TKA) length of stay (LOS), facility discharge, and clinically significant Veterans RAND-12 Physical Component Score (PCS) improvement.

Methods—We prospectively collected clinical data on 2,198 TKAs at a high-volume rural tertiary academic hospital from April 2011 through March 2016. SES variables included race/ethnicity, living alone, education, employment, and household income, along with numerous adjusting variables. We determined individual SES predictors and whether the inclusion of all SES variables contributed to each 10-fold cross-validated area under the model's area under the receiver operating characteristic (AUC). We also used 1000-fold bootstrapping methods to determine whether the SES and non-SES models were statistically different from each other.

Results—At least 1 SES predicted each outcome. Ethnic minority patients and those with incomes<$35,000 predicted longer LOS. Ethnic minority patients, the unemployed, and those living alone predicted facility discharge. Unemployed patients were less likely to achieve PCS improvement. Without the 5 SES variables, the AUC values of the LOS, discharge, and PCS

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models were 0.74 (95% CI 0.72–0.77, "acceptable"; 0.86 (CI 0.84–0.87, "excellent"); and 0.80 (CI 0.78–0.82, "excellent"), respectively. Including the 5 SES variables, the ten-fold cross-validated and bootstrapped AUC values were 0.76 (CI 0.74–0.79); 0.87 (CI 0.85–0.88); and 0.81 (0.79–0.83), respectively.

Conclusions—We developed validated predictive models for outcomes after TKA. Although inclusion of multiple SES variables provided statistical predictive value in our models, the amount of improvement may not be clinically meaningful.

Keywords

Total knee arthroplasty; socioeconomic status; length of stay; discharge disposition; patient-reported outcomes; predictive models

Introduction

Total knee arthroplasty (TKA) is an established cost-effective surgical procedure that is designed to relieve knee pain and disability.[1,2] From 2001 through 2011, TKA incidence increased 93% to 718,000 cases annually in the United States, and now has the third highest incidence of any surgical procedure.[3] In 2011, TKA had the second-highest aggregate costs for any surgery at $11.3 billion.[3] Due to its popularity, high cost, and lagging reimbursement rate,[4,5] TKA has been subjected to significant cost containment efforts by hospitals, insurers, and the government.[6] Despite this, high variations remain in TKA outcomes among U.S. hospitals, with potentially immense influence on patient quality of life, quality of care, and healthcare costs.[7]

Patient-reported outcomes (PROs) and quality reporting are evolving rapidly in medicine. However, these collection efforts may come at significant cost, time commitment, and data analysis: current estimates indicate that collection of external quality measures takes approximately 11 practice hours per orthopaedic surgeon per week (1 hour specifically by the physician) and approximately $31,500 per orthopaedic surgeon per year.[8] The Comprehensive Care for Joint Replacement (CJR) will likely increase these commitments further. These efforts may create large collection burdens for both practices and patients; for example, the 2,060 patients (2,198 TKAs) discussed in this article have given 1,314,420 answers to 2,238 different survey questions posed by our institution from April 2011 through March 2016.

Several preoperative factors have been noted to be associated with TKA outcomes, including gender,[9–12] age,[9–13] physical function,[9,12–14] mental function,[15] body mass index,[12,16] and medical comorbidities.[12,17] Little is known about how various demographic and socioeconomic status (SES) variables are associated with TKA outcomes after adjustment for other factors, although they are studied regularly across other medical disciplines.[18] Until recently, SES variables were rarely studied in Orthopaedics, particularly in rural areas for elective surgeries after adjusting for clinical, PROs, and multiple SES variables.[19–22] Even among these new reports, none used more than 1 self-reported SES measure in conjunction with patient-reported outcomes, nor provided comparative predictive models for whether SES variables independently contributed to models. It is possible that adding SES variables to TKA predictive models may offer diminishing returns and little contributory value.[23] Apart from race and ethnicity, SES variables are not collected currently in the American Joint Replacement Registry[24] or the Function and Outcomes Research for Comparative Effectiveness in Total Joint Replacement consortium (FORCE-TJR registry).[25]

We sought to determine whether five self-reported SES measures (race/ethnicity, living alone, education, employment, and household income) contribute independently and meaningfully to TKA outcome predictive models in a rural area, including length of stay (LOS) beyond 3 days, facility discharge, and clinically significant patient-reported improvement of physical function. We elected to only use preoperative variables that may be self-reported by the patient outside of a medical setting; other papers have noted the ability to create strong predictive models using only these types of variables.[15,23] We hypothesized that SES variables would predict each outcome in an adjusted multivariate model, and that the addition of SES variables would significantly improve each predictive model.

Materials and Methods

Setting

Our study uses data from our prospective Orthopaedic Operational Data Repository, at a rural tertiary academic medical center in northern New England, from April 2011 through March 2016. All variables are collected prospectively through the electronic medical record (EMR). Data collection was built into normal daily practice for all patients. Our institutional review board waived the requirement for individual informed consent. There were no exclusions among completed primary TKA procedures. The institutional arthroplasty clinical pathway went through a standardization process in April 2011 (concurrent with our EMR implementation) and did not vary significantly during the research time period.

Variables

The selected self-reported SES variables included race/ethnicity [non-Hispanic White (“white”) or not (“ethnic minority”: consisting of Asian, Black, Hispanic, and/or Native American), reflecting the demographics of rural New England; due to low counts, it would not be valid to investigate each race/ethnicity group separately], living alone (no, yes), completed education (postgraduate, college, some college, high school or less), employment (working/student, retired for non-health reasons, not working), and household income (more than $75,000, $50,000–75,000, $35,000–50,000, less than $35,000, and refused to answer).[26] We used the value closest to date of surgery for SES variables when captured multiple times for the same patient.

Among the available variables, we focused on the following preoperative adjusters: age,[12] gender,[12] surgeon,[12] alcohol use,[18] tobacco use,[18,27] Charlson Comorbidity Score,[12] Veterans RAND-12 (VR-12) physical component score (PCS),[12,28–30] VR-12 mental component score (MCS),[31] year of surgery, bilaterality,[32] and BMI.[12,16] Additionally, the PCS improvement model also includes an adjusting variable for the time period in which postoperative PCS was captured. Our PCS preoperative, postoperative, and both time period capture percentages are 92%, 79%, and 78%, respectively, which generally meet the PRO capture rates in the well-known AJRR, FORCE-TJR, and California Joint Replacement Registry (CJRR) registries.[33] Table 1 shows counts of each variable in our data set. We included SES missing values as their own category and retained them in all analyses and tables to determine whether those who did not answer or were not asked SES questions varied from patients who did. Only the SES variables had significant missingness. Missing values for other variables are included in the models and described in Table 1, but are not displayed.

Models

We included models for predicting three different outcomes for TKA: length of stay over 3 days (LOS, no/yes),[26] facility discharge (no/yes) (Table 2),[12] and clinically significant PCS improvement, determined as an improvement of at least 5 points on the normalized 0 – 100 scale (no/yes).[15,30] We used dichotomous outcomes to enable satisfactory predictive models. The change score was measured as the latest postoperative recorded PCS subtracted by the latest preoperative score. As this model necessitates completeness of scores from both time periods, only 1,723 TKAs (78.4%) were included in this model. All surgeries were used for the LOS and discharge models.

Analyses

All analyses were conducted using Stata MP12.[34] We used multivariate logistic regression models for all outcomes. To evaluate each model's ability to distinguish between the dichotomous outcomes, we determined the area under the receiver operating characteristic (AUC) curve with 10-fold cross-validation to estimate the AUC in sub-samples of our data.[23,35] An AUC from 0.70 to 0.80 is acceptable and 0.80 to 0.90 is excellent.[23,36] Models with and without the SES variables (race/ethnicity, living alone, education, employment, and household income) were both documented to determine whether the AUC cross-validation measurements improved (higher on scale of 0 – 1) with the SES variables. In addition to cross-validation, we also performed 1000-fold bootstrapping techniques to statistically compare the AUCs with and without SES variables.[37] All models clustered on the individual patient to account for separate contralateral primary TKAs for 138 patients and used robust standard errors to account for the observational nature of the study.

Results

Sample Characteristics

In the mentioned time period, the Department of Orthopaedics performed 2,198 primary TKAs among 2,060 individual patients. Of the surgeries, the patient mean age was 65.6 (SD 9.8, Range 26–90), 57.3% were female, 98.0% were white, and mean preoperative body mass index (BMI) was 32.4 (SD 7.4, range 16.0–70.4). Table 1 includes basic counts and categories of our variables of interest and adjusters.

Model 1: LOS over 3 days

Among our 2,198 surgeries, 22% had a LOS over 3 days (Table 1). Among the SES variables, both ethnic minority patients and those with annual household incomes under $35,000 predicted longer LOS (ORs 2.39 and 2.74, P=0.003 and P=0.017, respectively).

Living alone and "not working" trended towards longer LOS (P=0.074 and P=0.058, respectively). Surgeon, age ≥75, preoperative Charlson score higher than 0, patients with lower MCS, year of surgery, bilateral TKAs, and morbid obesity predicted higher odds of longer LOS (Table 3). Lower preoperative PCS scores strongly predicted longer LOS in a dose-response fashion. Alcohol use predicted against longer LOS. Without the 5 SES variables, the LOS predictive model had a ten-fold cross-validated and bootstrapped AUC of 0.74 (CI 0.72–0.77), indicating an acceptable predictive value;[23,35] adding the 5 SES variables slightly improved the AUC to 0.76 (CI 0.74–0.79), which was also considered acceptable. The difference between the AUCs was statistically significant (P<0.0001).

Model 2: Facility Discharge

Approximately 38% of surgeries had a facility discharge (Table 2). Among the SES variables, patients that were ethnic minorities (OR 4.43, P<0.001), lived alone (OR 2.62, P<0.001), and weren't working (OR 1.78, P=0.031) all independently predicted facility discharge. Among the adjusters (Table 4), surgeon, women, those with a Charlson score ≥2, year of surgery, and morbid obesity all predicted facility discharge. As expected, bilateral surgeries strongly predicted facility discharge, even after adjustment for other variables (OR 21.43, P<0.001). Older age, worse preoperative PCS, and worse preoperative MCS all had high dose-response predictive value for facility discharges. As with LOS, alcohol use was protective against facility discharge (OR 0.60, P<0.001). Without the 5 SES variables, the discharge predictive model had a validated and bootstrapped AUC of 0.86 (CI 0.84–0.87), indicating an excellent predictive value; adding the 5 SES variables only slightly improved the AUC to 0.87 (CI 0.85–0.88), which retains the excellent categorization. The difference between the AUCs was statistically significant (P=0.002).

Model 3: Clinically Significant PCS Improvement

Approximately 63% of surgeries resulted in clinically significant PCS improvement of at least 5 points[30] among patients with both preoperative and postoperative PCS. Only 1 SES was associated with PCS: patients who were not working predicted against significant improvement (OR 0.55, P=0.031). Among the adjusting variables (Table 5), tobacco users and those with a Charlson score of 1 (but not 2+) predicted against significant improvement. Bilateral surgeries predicted improvement. Worse PCS and longer post-operative follow-up were associated with much greater odds of improvement in a dose-response fashion. Worse MCS predicted against improvement, also in a dose-response manner. Without the 5 SES variables, the PCS predictive model had a validated and bootstrapped AUC of 0.80 (CI 0.78–0.82), indicating excellent predictive value; adding the 5 SES variables only slightly improved the AUC to 0.81 (CI 0.79–0.83), which retains the excellent categorization. The difference between the AUCs was statistically significant (P=0.019).

Overall SES Variables

At least 1 SES variable predicted each outcome after adjustment for several factors, including other SES variables. Race/ethnicity and employment status were significant in two models while living alone and household income were significant in one model. Education level did not predict any outcome. Patients missing a SES value did not vary statistically from other patients for any SES variable or TKA outcome (Tables 3–5). Additionally, the

Charlson Comorbidity Index, preoperative PCS and MCS, as well as bilateral surgeries, were all significantly predictive across all outcomes (LOS, discharge, and PCS improvement).

Overall Model Predictive Values

The LOS model was of acceptable predictive value, while the facility discharge and clinically significant PCS improvement models were of excellent predictive value. Despite SES variables statistically improving the predictive value of each model, the inclusion of the 5 SES variables did not change the category of predictive value for any model, and improved the models' value by either 0.01 or 0.02 on a 0.01 – 0.99 range. There were no differences in the values of cross-validated and bootstrapped AUC values across all models.

Sub-Analysis

In a sub-analysis (data not shown) that ran the same models but restricted to only patients that that had answered at least 1 SES variable, and typically answered all of them (n = 782, 804, and 631 respectively for each model), the results were generally similar with correspondingly lower statistical power. There were no differences in age, gender, Charlson, surgeon, or preoperative PCS/MCS between those patients who did and did not answer an SES question. The AUC difference for these smaller models, with and without SES variables for LOS, discharge, and PCS improvement was 0.04, 0.01, and 0.02, respectively.

Discussion

Among our 2,198 primary TKAs at a rural tertiary medical center, 22% of surgeries resulted in LOS over 3 days, 38% were sent to a facility after discharge, and 63% underwent clinically significant improvement in self-reported physical function. Our percentage of longer LOS compares favorably to a national sample of 25%, although our facility discharge rate is higher than a national total joint arthroplasty sample of 30%; when excluding bilateral surgeries, our facility discharge rate was 26%.[26,38] Along with our results, other studies have noted that despite TKA's cost-effectiveness,[1,2] many patients may not achieve significant improvement in physical function as measured by PRO change score.[15,39] In our work, 37% of surgeries did not result in clinically significant improvement in physical function. Future research should explore whether patient satisfaction has any relationship with their reported physical function improvement.

It is notable that all three models had at least "acceptable" predictability and two had "excellent" predictability using rigorous statistical techniques, with or without the SES variables. Additionally, none of our variables were clinical in nature, or were even specific to the knee: theoretically, all of our data could have been obtained using surveys without a physical visit. Other orthopaedic studies have noted the power of predictive models. Keeney et al in 2013 noted a cross-validated AUC of 0.89 for predicting spine surgery after non-traumatic occupational back injuries using only 3 variables, none of which were SES or demographic in nature; adding 17 more variables, all of which were significant bivariately, only minutely improved the cross-validated AUC to 0.93.[23]

In our “acceptable” LOS > 3 days model, ethnic minorities and low household income predicted longer LOS, while surgeon, age ≥75, Charlson score over 0, lower PCS, lower MCS, bilateral TKA, morbidly obese, and year of surgery also predicted longer LOS; alcohol use predicted lower LOS. These SES findings are similar to a national sample, which also reported that race and low incomes were associated with longer LOS, though that study did not have any other SES variables available.[26] Another study noted the association between income and LOS, although that study used census geographic income, didn’t adjust for other SES factors, and did not provide predictive models.[20] We could not locate another preoperative predictive model for longer TKA LOS among American hospitals.

Among the SES variables in our “excellent” predictive model for facility discharge, values for ethnic minority status, living alone, and not working individually predicted facility discharge. These models achieved very high predictive values of 0.87 and 0.86. Other studies have noted that ethnic minority status was associated with TKA discharge destination.[40,41] We could not locate another study that included living alone or unemployment as a predictor of TKA facility discharge, though Rissman 2016 noted that missing a status of living with others as a limitation, and Courtney 2016 noted a relationship between census-based income and discharge.[12,20]

In our “excellent” predictive model for clinically significant PCS improvement, the only significant SES variable was “not working”, which predicted lower odds of improvement. Goodman 2016 also noted an association between race/ethnicity and education with PROs (2-year WOMAC), but that the association was clinically small and did not meet their threshold.[19] Our AUC model values of 0.81 and 0.80 improve on another medical center’s model for PCS improvement of 5 points at 1 year, which had a multivariate predictive AUC value of 0.71 with fewer variables.[15] That model included SF-12 PCS and MCS, gender, age, and race. In a sub-analysis, we matched their variables to our data with only 1-year PCS follow-up measures and achieved an AUC of 0.77 (95% CI 0.73–0.81) (data not shown). With only 5 variables, none of which required a clinical visit or were specific to the knee, we obtained an AUC score within 0.04 of our larger multivariate model with 17 variables (Table 5).

These combined findings, combined with earlier papers,[15,23] give increasing credence that there are diminishing returns for adding more variables to predictive surgical models and that specific variables, especially preoperative physical function, are more important to collect than others.

Our study contains many limitations. Our missingness rates are high among all of our SES variables. It is possible that a higher capture rate may change our results, although our predictive models already present strong predictive ability. However, our patients who did not answer SES questions did not vary from those that did, and a smaller sub-model of surgeries with full SES capture had similar findings. Although our results were internally cross-validated and bootstrapped, our patient population consists of one large rural academic medical center and does not present substantial racial and ethnic diversity, although it is representative of the region and 88% of TKAs in the Medicare population continue to occur in the white population.[12,41] However, our population did present a large range of the other

SES variables. Lastly, SES variables may remain helpful for determining systematic outcomes or outreach concerns between different cohorts of patients across different institutions or in risk adjustment for other outcomes not documented here. However, we note that we have achieved excellent and acceptable predictive models without the inclusion of any SES variables for our outcomes of interest. Our study also contains several strengths: we have identified strong prospective predictive models for longer LOS, facility discharge, and clinically significant physical function improvement using only variables that may be determined by patients while accounting for numerous separate SES indicators.

Conclusions

We included several SES variables in multivariate predictive models for TKA outcomes in a rural area. At least 1 SES variable contributed individually to each model and the overall models statistically improved with their inclusion. However, the predictive improvement of the SES models was minor and one must consider whether the improved predictive power of AUC 0.01 or 0.02 justifies the additional efforts to collect these variables. As an institution, we will continue to collect these variables (race/ethnicity, living situation, education, employment, and household income) as they are already embedded in our patient pathway. However, other institutions may want to focus on other variables that offer more benefit for predictive modeling in the current joint replacement climate, particularly patient-reported measures like physical and mental function, prior to incorporating SES variables into their clinic workflow.

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Table 1

Counts of relevant variables within the institutional total knee arthroplasty repository (n=2,198 surgeries among 2,060 individuals)

Variable	Counts, N = 2,198	%
Race (ref = Non-Hispanic White)	2,153	98
Ethnic Minority	45	2
Living Alone (ref = No)	483	22
Yes	162	7
Missing	1,553	71
Education (ref = Postgrad)	183	8
College	165	8
Some College	190	9
High School or Less	224	10
Missing	1,436	65
Employment (ref = Working/Student)	254	12
Retired, Not Health Related	276	13
Not Working	232	11
Missing	1,436	65
Household Annual Income (ref = $75,000+)	124	6
$50–75,000	92	4
$35–50,000	72	3
<$35,000	128	6
Refused to Answer	150	7
Missing	1,632	74
Surgeon (ref = Surgeon 1)	541	25
Surgeon 2	363	17
Surgeon 3	29	1
Surgeon 4	4	0.2
Surgeon 5	51	2
Surgeon 6	358	16
Surgeon 7	425	19
Surgeon 8	109	5
Surgeon 9	80	4
Surgeon 10	238	11
Age Group (ref = <55)	301	14
55–59	323	15
60–64	399	18
65–69	462	21
70–74	328	15
75–79	223	10

Variable	**Counts, N = 2,198**	**%**
80+	162	7
Sex (ref = Male)	938	43
Female	1,260	57
Preoperative Alcohol Use (ref = No)	804	38
Yes	1,305	62
Preoperative Tobacco Use (ref = Never)	1,009	47
Quit	999	46
Yes	151	7
Charlson Score (ref = 0)	1,284	58
1	456	21
2+	458	21
PCS Preoperative Mean (SD, Range), n = 2,012	31.2 (11.0, 6.9 – 70.4)	
50+	138	7
40–49.99	301	15
30–39.99	479	24
20–29.99	802	40
<20	292	15
VR-12 MCS Preoperative Mean (SD, Range)	53.4 (13.2, 18.4 – 75.1)	
60+	844	42
50–59.99	469	23
40–49.99	301	15
30–39.99	257	13
<30	141	7
VR-12 PCS Post-Op Mean (SD, Range), n = 1,812	41.3 (12.5, 8.5 – 64.8)	
VR-12 PCS Post-Op Time Period (ref = 0 – 45 Days Post-Operative) [a]	268	16
46 – 299 Days Post-Operative	512	30
300 – 420 Days Post-Operative (1 Year)	720	42
421 + Days Post-Operative	225	13
Year (ref = April – December 2011)	321	15
2012	505	23
2013	522	24
2014	403	18
2015	368	17
January – March 2016	79	4
Bilateral TKA (ref = No)	1,687	77
Yes	511	23
BMI Preoperative Mean (SD, Range) [b]	32.4 (7.4, 16.0 – 70.4)	
Normal, <25	279	14
Overweight, 25–29.99	602	30

Variable	Counts, N = 2,198	%
Obese, 30–34.99	488	24
Severe Obese, 35–39.99	345	17
Morbid Obese, 40+	290	14
Length of Stay, Days Mean (SD, Range)	3.0 (1.5, 1 – 30)	
1	140	6
2	680	31
3	901	41
4	291	13
5	97	4
6	42	2
7	19	1
8	9	0
9	8	0
11	2	0
12	2	0
13	2	0
14	2	0
15	1	0
21	1	0
30	1	0
Length of Stay (ref <4 Days)	1,721	78
> 3 Days	477	22
Discharge Disposition		
Home	1,364	62
Facility	832	38
PCS Improvement Mean (SD, Range)	10.1 (13.9, −39.5 – 44.5)	
PCS Clinically Significant Improvement (VR-12 Post-Operative – VR-12 Pre-Operative), >5 score increase (ref = No)	642	37
Yes	1,083	63

Some additional non-SES variables have minor missingness for all tables and models. These surgeries contained categories of missing and were included in the models, but are not displayed. Their counts include postoperative VR12 PCS (n=386, 18%), preoperative BMI (n=194, 9%), preoperative VR12 PCS (186, 8%), preoperative VR12 MCS (186, 8%), preoperative alcohol use (89, 4%), preoperative tobacco use (31, 1%), and discharge disposition (2 hospital deaths, 0%). Tobacco use also included a measure of “Passive”, which only had 8 surgeries; this value was retained in the models but is not displayed.

[a]Only includes post-operative scores among surgeries that also had a pre-operative score. Of the 2,198 surgeries, 2,012 (91%) had a pre-operative VR-12, 1,812 (82%) had a post-operative VR-12, and 1,725 (79%) had both pre-operative and postoperative.

[b]BMI was calculated from height and weight measurements collected within clinic visits and were not self-reported.

Table 2

Definition and counts of home and inpatient discharge, as reported in EMR.

Discharge Type	Count	%	Discharge Category
Custodial Care	1	0.1	Home
Deceased before discharge	2	0.1	--
Home	60	2.7	Home
Home with Visiting Nurse	1,303	59.3	Home
Intermediate Care Facility	1	0.1	Facility
Other Short Term General Hospital	1	0.1	Facility
Psychiatric Hospital – Stand Alone	1	0.1	Facility
Rehabilitation Center in a Facility	15	0.7	Facility
Rehabilitation Center –Acute Care	209	9.5	Facility
Rehabilitation Center –Stand Alone	91	4.1	Facility
Skilled Nursing Facility	244	11.1	Facility
Swing Bed	270	12.3	Facility
Total	2,198	100	Home 1,364 (62.1%), Facility 832 (37.9%)

Table 3

Multivariate logistic model for whether separate SES variables individually predict LOS>3 days (22%) among primary TKAs (n=2,194)

	With SES Variables			**No SES Variables**		
Variable	**OR**	**95% CI**	**P-Value**	**OR**	**95% CI**	**P-Value**
Race (ref = Non-Hispanic White)						
Other	2.39	1.35–4.25	**0.003**	--	--	--
Living Alone (ref = No)						
Yes	1.60	0.96–2.67	0.074	--	--	--
Missing	1.42	0.69–2.89	0.340	--	--	--
Education (ref = Postgrad)						
College	1.51	0.79–2.88	0.216	--	--	--
Some College	1.19	0.62–2.31	0.601	--	--	--
High School or Less	1.29	0.68–2.44	0.430	--	--	--
Missing	1.00	0.30–3.28	0.996	--	--	--
Employment (ref = Working/Student)						
Retired, Not for Health	0.81	0.47–1.39	0.440	--	--	--
Not Working	1.65	0.98–2.77	0.058	--	--	--
Missing	1.24	0.40–3.82	0.709	--	--	--
Household Annual Income (ref = $75,000+)						
$50–75,000	2.16	0.88–5.32	0.093	--	--	--
$35–50,000	0.78	0.28–2.20	0.643	--	--	--
<$35,000	2.74	1.20–6.25	**0.017**	--	--	--
Refused to Answer	1.15	0.51–2.62	0.732	--	--	--
Missing	1.99	0.80–4.91	0.137	--	--	--
Surgeon (ref = Surgeon 1)						
Surgeon 2	2.60	1.76–3.84	**<0.001**	2.61	1.78–3.83	**<0.001**
Surgeon 3	2.64	0.90–7.73	0.077	2.48	0.86–7.12	0.091
Surgeon 4*	--	--	--	--	--	--
Surgeon 5	1.44	0.56–3.71	0.449	1.45	0.58–3.61	0.426
Surgeon 6	1.82	1.23–2.70	**0.003**	1.82	1.23–2.70	**0.003**

	With SES Variables			No SES Variables		
Variable	**OR**	**95% CI**	**P-Value**	**OR**	**95% CI**	**P-Value**
Surgeon 7	2.62	1.81–3.78	**<0.001**	2.65	1.85–3.81	**<0.001**
Surgeon 8	1.06	0.56–2.03	0.857	1.14	0.61–2.15	0.675
Surgeon 9	0.49	0.17–1.40	0.183	0.52	0.18–1.48	0.218
Surgeon 10	1.73	1.10–2.73	**0.018**	1.70	1.08–2.67	**0.022**
Age Group (ref = <55)						
55–59	0.95	0.62–1.45	0.800	0.91	0.60–1.39	0.670
60–64	0.90	0.60–1.36	0.629	0.88	0.59–1.32	0.538
65–69	1.20	0.82–1.78	0.350	1.17	0.80–1.72	0.427
70–74	1.29	0.83–2.02	0.260	1.22	0.79–1.87	0.375
75–79	2.11	1.32–3.36	**0.002**	1.89	1.21–2.97	**0.005**
80+	2.58	1.56–4.26	**<0.001**	2.38	1.45–3.89	**0.001**
Sex (ref = Male)						
Female	1.20	0.95–1.53	0.123	1.24	0.98–1.56	0.072
Preoperative Alcohol Use (ref = No)						
Yes	0.71	0.55–0.90	**0.004**	0.66	0.52–0.84	**0.001**
Preoperative Tobacco Use (ref = Never)						
Quit	1.18	0.93–1.49	0.176	1.20	0.95–1.52	0.127
Yes	1.15	0.70–1.88	0.577	1.29	0.80–2.09	0.296
Charlson Score (ref = 0)						
1	1.41	1.06–1.86	**0.016**	1.38	1.05–1.84	**0.021**
2+	1.64	1.22–2.20	**0.001**	1.62	1.22–2.17	**0.001**
VR-12 PCS Preoperative (ref = 50+)						
40–49.99	2.43	1.17–5.01	**0.017**	2.62	1.28–5.36	**0.008**
30–39.99	2.99	1.49–5.96	**0.002**	3.20	1.62–6.32	**0.001**
20–29.99	2.94	1.48–5.85	**0.002**	2.17	1.62–6.23	**0.001**
<20	4.55	2.18–9.46	**<0.001**	4.93	2.41–10.09	**<0.001**
VR-12 MCS Preoperative (ref = 60+)						
50–59.99	1.17	0.85–1.60	0.328	1.23	0.90–1.67	0.198

	With SES Variables			No SES Variables		
Variable	**OR**	**95% CI**	**P-Value**	**OR**	**95% CI**	**P-Value**
40–49.99	1.53	1.08–2.17	**0.017**	1.63	1.15–2.31	**0.006**
30–39.99	1.94	1.32–2.84	**0.001**	2.10	1.44–3.07	**<0.001**
<30	1.30	0.76–2.23	0.342	1.36	0.80–2.30	0.255
Year (ref = 2011)						
2012	0.61	0.42–0.91	**0.015**	0.64	0.44–0.95	**0.026**
2013	0.73	0.49–1.09	0.123	0.66	0.45–0.96	**0.032**
2014	0.80	0.51–1.25	0.324	0.75	0.48–1.15	0.189
2015	0.47	0.28–0.78	**0.004**	0.41	0.25–0.68	**0.012**
2016	0.37	0.13–1.03	0.055	0.36	0.14–0.97	**0.042**
Bilateral TKA (ref = No)						
Yes	2.53	1.96–3.27	**<0.001**	2.39	1.86–3.08	**<0.001**
BMI Preoperative (ref = Normal, <25)						
Overweight, 25–29.99	0.94	0.63–1.39	0.741	0.91	0.62–1.35	0.648
Obese, 30–34.99	1.10	0.73–1.65	0.641	1.11	0.75–1.65	0.597
Severe Obese, 35–39.99	1.28	0.83–1.98	0.258	1.32	0.86–2.02	0.200
Morbid Obese, 40+	1.61	1.02–2.55	**0.040**	1.64	1.04–2.56	**0.031**
10-fold cross-validation AUC						
	0.76	0.74–0.79		0.74	0.72–0.77	

Clustered on 2,057 patients and using robust standard errors to account for observational data. Surgeon 4 performed 4 surgeries in this time period and they were excluded from this analysis for lack of variation.

Table 4

Multivariate logistic model for whether separate SES variables individually predict facility discharge (37.9%) among primary TKAs (n=2,196)[a]

	With SES Variables			No SES Variables		
Variable	**OR**	**95% CI**	**P-Value**	**OR**	**95% CI**	**P-Value**
Race (ref = Non-Hispanic White)						
Other	4.43	2.03–9.64	**<0.001**	--	--	--
Living Alone (ref = No)						
Yes	2.62	1.62–4.23	**<0.001**	--	--	--
Missing	0.83	0.44–1.58	0.577	--	--	--
Education (ref = Postgrad)						
College	0.92	0.50–1.67	0.778	--	--	--
Some College	1.19	0.67–2.13	0.555	--	--	--
High School or Less	1.01	0.56–1.82	0.965	--	--	--
Missing	1.08	0.41–2.81	0.878	--	--	--
Employment (ref = Working/Student)						
Retired, Not for Health	1.25	0.75–2.06	0.390	--	--	--
Not Working	1.78	1.05–3.01	**0.031**	--	--	--
Missing	1.12	0.43–2.91	0.823	--	--	--
Household Annual Income (ref = $75,000+)						
$50–75,000	1.06	0.50–2.28	0.875	--	--	--
$35–50,000	0.76	0.34–1.68	0.498	--	--	--
<$35,000	0.94	0.46–1.92	0.864	--	--	--
Refused to Answer	0.58	0.29–1.15	0.117	--	--	--
Missing	1.22	0.58–2.54	0.596	--	--	--
Surgeon (ref = Surgeon 1)						
Surgeon 2	1.69	1.13–2.53	**0.011**	1.66	1.12–2.46	**0.012**
Surgeon 3	0.48	0.15–1.55	0.220	0.51	0.16–1.57	0.239
Surgeon 4	0.93	0.19–4.48	0.931	0.82	0.17–3.99	0.809
Surgeon 5	1.52	0.69–3.31	0.295	1.72	0.79–3.76	0.176

	With SES Variables			No SES Variables		
Variable	**OR**	**95% CI**	**P-Value**	**OR**	**95% CI**	**P-Value**
Surgeon 6	0.83	0.56–1.24	0.367	0.83	0.56–1.25	0.375
Surgeon 7	1.06	0.74–1.51	0.752	1.10	0.78–1.55	0.598
Surgeon 8	1.29	0.76–2.20	0.350	1.31	0.77–2.23	0.321
Surgeon 9	0.45	0.19–1.08	0.073	0.47	0.19–1.15	0.099
Surgeon 10	1.10	0.71–1.69	0.682	1.09	0.71–1.66	0.706
Age Group (ref = <55)						
55–59	1.36	0.83–2.23	0.224	1.30	0.80–2.13	0.289
60–64	2.41	1.50–3.88	**<0.001**	2.33	1.45–3.74	**<0.001**
65–69	4.42	2.75–7.10	**<0.001**	4.20	2.63–6.71	**<0.001**
70–74	7.49	4.56–12.31	**<0.001**	7.14	4.38–11.65	**<0.001**
75–79	16.65	9.55–29.03	**<0.001**	15.66	9.12–26.91	**<0.001**
80+	20.38	11.22–37.02	**<0.001**	18.75	10.44–33.67	**<0.001**
Sex (ref = Male)						
Female	2.00	1.56–2.57	**<0.001**	2.07	1.62–2.66	**<0.001**
Preoperative Alcohol Use (ref = No)						
Yes	0.60	0.47–0.78	**<0.001**	0.60	0.47–0.76	**<0.001**
Preoperative Tobacco Use (ref = Never)						
Quit	1.03	0.80–1.33	0.792	1.06	0.83–1.36	0.620
Yes	1.22	0.71–2.11	0.477	1.29	0.76–2.19	0.353
Charlson Score (ref = 0)						
1	1.23	0.92–1.66	0.162	1.23	0.92–1.64	0.163
2+	1.55	1.14–2.10	**0.005**	1.53	1.13–2.06	**0.005**
VR-12 PCS Preoperative (ref = 50+)						
40–49.99	2.38	1.33–4.23	**0.003**	2.53	1.44–4.44	**0.001**
30–39.99	2.53	1.47–4.37	**0.001**	2.74	1.60–4.68	**<0.001**
20–29.99	3.43	2.02–5.82	**<0.001**	3.69	2.19–6.22	**<0.001**
<20	4.91	2.66–9.05	**<0.001**	5.25	2.89–9.52	**<0.001**
VR-12 MCS Preoperative (ref = 60+)						

	With SES Variables			No SES Variables		
Variable	**OR**	**95% CI**	**P-Value**	**OR**	**95% CI**	**P-Value**
50–59.99	1.64	1.20–2.24	**0.002**	1.64	1.21–2.21	**0.001**
40–49.99	2.53	1.75–3.66	**<0.001**	2.59	1.81–3.73	**<0.001**
30–39.99	2.91	1.89–4.47	**<0.001**	2.94	1.92–4.49	**<0.001**
<30	2.29	1.32–3.99	**0.003**	2.26	1.32–3.85	**0.003**
Year (ref = 2011)						
2012	1.38	0.89–2.14	0.145	1.43	0.94–2.19	0.098
2013	1.76	1.13–2.75	**0.013**	1.84	1.21–2.81	**0.005**
2014	1.40	0.86–2.27	0.171	1.48	0.93–2.34	0.098
2015	1.16	0.68–1.97	0.588	1.13	0.68–1.89	0.640
2016	1.70	0.74–3.93	0.213	1.67	0.75–3.73	0.208
Bilateral TKA (ref = No)						
Yes	21.43	15.72–29.23	**<0.001**	18.99	14.04–25.69	**<0.001**
BMI Preoperative (ref = Normal, <25)						
Overweight, 25–29.99	0.92	0.62–1.36	0.661	0.93	0.63–1.36	0.694
Obese, 30–34.99	1.27	0.85–1.91	0.245	1.30	0.88–1.93	0.193
Severe Obese, 35–39.99	1.27	0.82–1.98	0.290	1.27	0.82–1.96	0.276
Morbid Obese, 40+	3.89	2.44–6.20	**<0.001**	3.81	2.40–6.03	**<0.001**
10-fold cross-validation AUC						
	0.87	0.85 – 0.88		0.86	0.84 – 0.87	

Clustered on 2,059 patients and using robust standard errors to account for observational data

[a] 2 in-hospital deaths occurred and were not discharged.

Table 5

Multivariate logistic model for whether separate SES variables individually predict clinically significant PCS improvement (5 points yes/no, 63% clinically significant improvement) among primary TKAs (n=1,723)

	With SES Variables			No SES Variables		
Variable	**OR**	**95% CI**	**P-Value**	**OR**	**95% CI**	**P-Value**
Race (ref = Non-Hispanic White)						
Other	0.78	0.34–1.79	0.556	--	--	--
Living Alone (ref = No)						
Yes	1.18	0.69–2.03	0.548	--	--	--
Missing	1.36	0.66–2.77	0.405	--	--	--
Education (ref = Postgrad)						
College	0.89	0.49–1.62	0.698	--	--	--
Some College	1.06	0.59–1.90	0.852	--	--	--
High School or Less	1.43	0.76–2.67	0.266	--	--	--
Missing	2.26	0.83–6.16	0.111	--	--	--
Employment (ref = Working/Student)						
Retired, Not for Health	0.67	0.39–1.14	0.136	--	--	--
Not Working	0.55	0.32–0.95	**0.031**	--	--	--
Missing	0.55	0.22–1.40	0.208	--	--	--
Household Annual Income (ref = $75,000+)						
$50–75,000	0.74	0.33–1.67	0.469	--	--	--
$35–50,000	1.83	0.72–4.63	0.203	--	--	--
<$35,000	1.32	0.58–3.00	0.506	--	--	--
Refused to Answer	0.98	0.49–1.98	0.961	--	--	--
Missing	0.53	0.24–1.16	0.110	--	--	--
Surgeon (ref = Surgeon 1)						
Surgeon 2	0.94	0.62–1.42	0.755	0.91	0.61–1.36	0.649
Surgeon 3 *	--	--	--	--	--	--
Surgeon 4	0.68	0.24–1.89	0.457	0.66	0.23–1.86	0.431
Surgeon 5	0.89	0.61–1.28	0.530	0.89	0.62–1.27	0.512

	With SES Variables			No SES Variables		
Variable	**OR**	**95% CI**	**P-Value**	**OR**	**95% CI**	**P-Value**
Surgeon 6	0.92	0.65–1.31	0.645	0.91	0.64–1.28	0.574
Surgeon 7	0.65	0.34–1.26	0.202	0.62	0.32–1.19	0.149
Surgeon 8	1.49	0.64–3.48	0.353	1.21	0.53–2.75	0.646
Surgeon 9	0.92	0.60–1.41	0.695	0.89	0.58–1.35	0.574
Age Group (ref = <55)						
55–59	0.82	0.52–1.28	0.375	0.80	0.51–1.24	0.314
60–64	1.24	0.81–1.91	0.315	1.18	0.78–1.79	0.438
65–69	1.00	0.65–1.55	0.999	0.93	0.61–1.42	0.747
70–74	0.94	0.58–1.53	0.808	0.88	0.55–1.40	0.586
75–79	0.79	0.45–1.37	0.398	0.72	0.42–1.22	0.221
80+	0.63	0.36–1.10	0.105	0.61	0.35–1.06	0.080
Sex (ref = Male)						
Female	1.07	0.83–1.37	0.609	1.05	0.82–1.34	0.702
Preoperative Alcohol Use (ref = No)						
Yes	1.06	0.82–1.37	0.663	1.01	0.79–1.31	0.912
Preoperative Tobacco Use (ref = Never)						
Quit	0.83	0.64–1.07	0.154	0.83	0.64–1.07	0.151
Yes	0.59	0.37–0.96	**0.033**	0.58	0.36–0.92	**0.020**
Charlson Score (ref = 0)						
1	0.71	0.53–0.95	**0.023**	0.71	0.53–0.95	**0.019**
2+	0.85	0.62–1.16	0.306	0.83	0.61–1.13	0.235
VR-12 PCS Preoperative (ref = 50+)						
40–49.99	6.31	3.22–12.36	**<0.001**	6.23	3.22–12.07	**<0.001**
30–39.99	25.69	13.25–49.81	**<0.001**	24.80	12.89–47.74	**<0.001**
20–29.99	38.79	19.95–75.39	**<0.001**	37.25	19.33–71.79	**<0.001**
<20	57.48	26.97–122.48	**<0.001**	54.09	25.66–114.05	**<0.001**
VR-12 MCS Preoperative (ref = 60+)						
50–59.99	0.99	0.73–1.34	0.948	0.97	0.72–1.31	0.836

	With SES Variables			No SES Variables		
Variable	**OR**	**95% CI**	**P-Value**	**OR**	**95% CI**	**P-Value**
40–49.99	0.51	0.35–0.73	**<0.001**	0.50	0.35–0.70	**<0.001**
30–39.99	0.42	0.27–0.65	**<0.001**	0.42	0.28–0.65	**<0.001**
<30	0.35	0.20–0.59	**<0.001**	0.35	0.21–0.60	**<0.001**
VR-12 PCS Post-Op Time Period (ref = 0 – 45 Days)						
46 – 299 Days	4.51	3.10–6.55	**<0.001**	4.43	3.06–6.39	**<0.001**
300 – 420 Days	7.15	4.73–10.79	**<0.001**	6.86	4.55–10.32	**<0.001**
421 + Days	7.09	4.34–11.60	**<0.001**	6.90	4.23–11.27	**<0.001**
Year (ref = 2011)						
2012	0.96	0.60–1.53	0.863	0.96	0.61–1.51	0.850
2013	1.00	0.62–1.60	0.989	1.00	0.64–1.58	0.983
2014	0.68	0.40–1.14	0.143	0.69	0.41–1.14	0.145
2015	0.86	0.46–1.61	0.643	0.88	0.48–1.61	0.678
Bilateral TKA (ref = No)						
Yes	1.77	1.30–2.42	**<0.001**	1.75	1.29–2.37	**<0.001**
BMI Preoperative (ref = Normal, <25)						
Overweight, 25–29.99	0.96	0.65–1.42	0.854	0.92	0.63–1.36	0.689
Obese, 30–34.99	0.70	0.46–1.06	0.092	0.66	0.44–1.01	0.053
Severe Obese, 35–39.99	0.76	0.48–1.21	0.252	0.73	0.46–1.15	0.171
Morbid Obese, 40+	0.71	0.44–1.14	0.155	0.68	0.42–1.08	0.102
10-fold cross-validation AUC						
	0.81	0.79–0.83		0.80	0.78–0.82	

Clustered on 1,723 patients and using robust standard errors to account for observational data

Surgeon 3 performed 2 surgeries with pre-operative and post-operative VR-12 scores and was excluded from analysis.

Among patients that completed VR-12s at multiple post-operative time periods, the order of priority for this model was 300 – 420 days, more than 421 days, 46 – 299 days, and 0 – 45 days post-operative.