A Joint Effort: Community-Level Social Determinants of Health May be More Important Than Race in the Machine Learning Prediction of Adverse Outcomes after Total Knee Arthroplasty

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INTRODUCTION: Rates of total knee arthroplasty (TKA) utilization in the United States (US) have risen, but the benefits of this procedure for the treatment of degenerative joint disease may not be experienced among all patients. Racial and ethnic disparities affecting TKA outcomes are well-documented in literature, and it is known that Black patients are less likely to undergo TKA and are more susceptible to poor outcomes compared to White patients. The impact of other social determinants of health (SDOH) has not been fully investigated, and most studies have exclusively explored socioeconomic status (SES) or community variables independently. In this study, we utilize a highly interpretable machine learning model - explainable boosting machine (EBM) - to understand and compare the importance of community-level SDOH with that of patient-level factors such as race on adverse TKA outcomes including 90-day mortality, 90-day readmission, 1-year revision, and longer length of stay (LOS).

METHODS: A total of 258,724 patients who underwent primary elective TKA between 2012-2018 were identified from the Pennsylvania Health Care Cost Containment Council Database by ICD codes, and 43,310 patients with complicating history (e.g., rheumatoid arthritis, pathologic fracture) were excluded. Individual-level factors (e.g., age, sex, race) and comorbidities were extracted. Census-tract level community factors were extracted from the US census via geocoding, including: 1) internet access (%), 2) computer access (%), 3) unpaid family workers (%), 4) living alone (%), 5) no insurance or unemployed (%), 6) high school or college and above education (%), 7) median income, 8) National Walkability index, and 9) total foreign born (%), and 10) speaking a language other than English (%). Descriptive statistics were performed to compare patient- and community-level factors for binary 90-day readmission, 90-day mortality, and 1-year revision. Categorical variables were compared using Pearson's *Chi*-squared/Fisher's exact, and continuous variables were compared using Wilcoxon rank sum test. Significance was $p<0.05$. LOS was transformed (log(LOS+0.5)) to avoid numerical problems with log transform. EBMs, a modern form of generalized additive model (GAM), were utilized to predict risk for each TKA outcome. Area under the receiver operating curve (AUROC) and root mean squared error (RMSE) were reported as evaluation metrics. Models were trained and tested using random train and test split (70% train:30% test) and cross validation techniques to reduce overfitting and ensure robustness. We measured feature importance for each variable using the mean absolute score (MAS). The "community" variable, an aggregate of the 10 features, was run through the learned shape function of the EBM one feature at a time. We then combined the weighted-average importance scores, which we describe as "community" factors. We computed missing values from the community factors and reran each model. This study was IRB exempt.

RESULTS: Our cohort of 215,414 patients was 90.3% White, 9.7% Black or other race, and 62.1% female. The median age at time of TKA was 66 years (IQR [60.0, 73.0]). 16,518 (7.67%) patients were readmitted and 497 (0.23%) died within 90 days of surgery, 1,720 (0.80%) patients underwent 1-year revision, and the median LOS was 2 days (IQR [2, 3]) (Table 1). Patients who experienced these outcomes were more likely to be residents of communities with a lower median household income and with a greater percentage of householders living alone and lacking insurance coverage, among other unfavorable community factors. Model predictive performance was highest for mortality (AUROC=0.74), followed by readmission (AUROC=0.64), revision (AUROC=0.62), and LOS (RMSE=0.35, r^2=0.2) (Figure 1). The MAS for "community" factors were more important than race in each of our examined models, even with the models accounting for patient age, sex, and comorbidities. Race was among the least important factors for each model, whereas "community" factors were among the top five most important.

DISCUSSION: Our supervised machine learning models demonstrated that community-level factors are more important than race in the prediction of poor outcomes after TKA. Our models accounted for important patient-level factors such as patient age, sex, and comorbidities, yet still identified community factors among the top five most important factors in the prediction of each examined adverse outcome. We observed that patient-level factors, including older age and Black race, increase risk for outcomes including mortality, which is consistent with literature. While patient-level SDOH such as SES or income also have known associations with poor TKA outcomes, we further explored these SDOH at the community-level to highlight the importance of these previously unexplored factors in discussion and consideration of TKA.

SIGNIFICANCE/CLINICAL RELEVANCE: Stakeholders in TKA should carefully consider the community-level factors that influence the daily and healthcare experiences of patients to identify those at increased risk for adverse outcomes after TKA including mortality, readmission, revision, and longer LOS. This may shape institutional resource allocation and health policy to optimize and mitigate disparities in outcomes after TKA. For example, surgeons may identify patients living in communities with unfavorable community factors, and coordinate support and follow-up with social work or home health and rehabilitation programs. These SDOH may also be modified in the pre-operative period, such as by providing informational packets or seminars for patients without computer/internet access.

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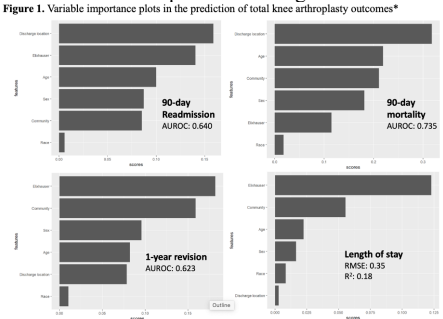
Table 1. Patient-level and community-level characteristics of the cohort

Variable	n=215,414	Variable	n=215,414
Age	66.0 [60.0, 73.0]	Hypertension	71806 (33.3%)
Sex		Diabetes	22209 (10.3%)
Female	133765 (62.1%)	Obesity	29422 (13.7%)
Male	81649 (37.9%)	**Community-level factors**	
Race		Internet access, %	76.8 [72.3, 82.9]
White	194213 (90.3%)	Computer access, %	85.2 [81.4, 88.7]
Other	20953 (9.74%)	Unpaid family workers, %	0.11 [0.05, 0.2]
Discharge location		Living alone, %	11.4 [9.42, 13.8]
Health home / home	79664 (37.0%)	Without insurance coverage, %	5.90 [4.43, 7.86]
IRF	111726 (51.9%)	High school education or above, %	91.2 [88.1, 93.7]
SNF	24024 (11.2%)	College education or above, %	25.6 [19.2, 36.9]
Insurance		Median household income	58289 [49547, 72044]
Commercial	85186 (39.5%)	National Walkability Index	8.6 [7.2, 11.6]
Government	1323 (0.6%)	Foreign born, %	3.9 [1.6, 8.0]
Medicare/Medicaid	127625 (59.2%)	Speaking language other than English, %	2.2 [1.0, 4.1]
Unknown/Uninsured	1280 (0.6%)		
Length of stay	3.00 [2.00, 3.00]		
Elixhauser Comorbidity index	1.00 [0.00, 3.00]		

Categorical variables N (%). Continuous variables median [IQR].
IRF, independent rehabilitation facility; SNF, skilled nursing facility.

Figure 1. Variable importance plots in the prediction of total knee arthroplasty outcomes*



* "Community" is the aggregate mean absolute score for % householder living alone, % foreign born, % speaking language other than English, % with computer access, % with internet access, national walkability index, % not in labor force without insurance, % above high school, % above college, % with unpaid family workers, and median household income. These variables were extracted from American Community Survey or calculated by the National Walkability Index software from patient zip code.