

What is the Optimal Age for Total Hip Arthroplasty? Machine Learning Analysis of a Statewide Dataset

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INTRODUCTION: Total hip arthroplasty (THA) is performed to improve pain and function in degenerative joint disease such as osteoarthritis. Utilization of the procedure has grown dramatically, and recipient demographics are changing as both younger and older patients are electing the procedure. Postoperative THA complications have decreased with advancements in surgical techniques and perioperative planning, yet complications still occur and are important in discussion of THA. Age is known to be an important factor in THA outcomes such as mortality. In this study we utilize supervised machine learning to explore the effect of age as a risk factor for adverse THA outcomes and determine the optimal age for lowest risk of adverse outcomes.

METHODS: A total of 146,069 patients undergoing primary elective THA from 2012-2018 were identified from the Pennsylvania Cost Containment Database using ICD codes, and 40,733 patients with ICD codes indicating factors complicating THA (e.g., inflammatory arthritis, pathologic fracture) were excluded. Patient-level covariates (demographics, discharge location, admission source, insurance, comorbidities) were extracted and compared for binary outcomes 90-day readmission, 90-day mortality, and 1-year revision. Categorical variables were compared using Pearson's *Chi*-squared/Fisher's exact test, and continuous variables were compared using Wilcoxon rank sum test. Significance was $p < 0.05$. To avoid numerical problems, length of stay (LOS) was transformed (equation: $\log(\text{LOS} + 0.5)$). Age was examined as a risk factor for the binary outcomes as well as the continuous outcome LOS using an explainable boosting machine (EBM) with a 70%:30% train-test split. EBMs are a highly flexible and interpretable form of generalized additive models that measure feature importance both individually and as a group through automatic pairwise detection. The predictive performance of the EBM model was described by area under the receiver operating curve (AUROC) for binary outcomes and root mean square error (RMSE) for continuous outcomes. The marginal relationship of age on adverse outcomes both with and without predictive factors was characterized by partial dependency plots.

RESULTS: Our cohort of 105,336 patients who underwent primary elective THA was 90.1% White, 51.6% Medicare-insured, and 54.1% female (Table 1). The incidence of 90-day readmission was 8.00%, 90-day mortality was 0.29%, and 1-year revision was 1.54%. The median LOS was 2 days (IQR [1, 3]). Age was among the most important factors in our models for the prediction of each adverse outcome, even when including important patient-level factors such as race, sex, and comorbidities. Predictive performance (AUROC) was highest for prediction of 90-day mortality at 0.80, followed by 0.67 for 90-day readmission and 0.60 for 1-year revision. The RMSE was 0.41 and r^2 was 0.19 for our model predicting LOS (Figure 1). Our EBM models visualized the relationship between age and adverse outcomes, and demonstrated that risk for 90-day mortality increased at 79.5 years, and again dramatically at 80.5 years. Conversely, risk of 1-year revision decreased at the age of 46.5 years, whereas risk of 90-day readmission decreased at 48.5 years but increased at 71.5 years. LOS risk decreased at 52.5 years and increased at 74.5 years (Figure 1). Several factors influenced the relationship between age and adverse THA outcomes, and we found that risk for adverse outcomes changed at several time points (Figure 2). Discharge location was an important factor for each examined outcome, and other notable findings included increased readmission risk in patients with government or commercial insurance after 62 years and decreased risk for longer LOS in uninsured or unknown and Medicare or Medicaid patients after 63.5 years.

DISCUSSION: Our retrospective analysis demonstrated that risk for 90-day mortality, 90-day readmission, 1-year revision, and longer LOS changes dramatically at different time points across the patient lifespan. The optimal age for THA with lowest risk for adverse outcomes may be between 52.5 and 71.5 years, which provides greater nuance to the current understanding of age and THA outcomes. Most studies exploring risk factors such as age utilize parametric models (e.g., logistic regression), which provide a fixed odds ratio for an age or age range where risk for adverse outcomes changes. Given the complex and nonlinear relationship between age and THA outcomes, supervised machine learning provides a much more nuanced and flexible visualization of risk that provides specific ages at which risk changes, as well as the interacting patient-level factors.

SIGNIFICANCE: The optimal age for lowest risk of adverse outcomes after THA may be between 52.5 and 71.5 years, and patient covariates that interact with the relationship of age and THA outcomes, such as discharge location, should be considered in stakeholder discussion and planning of THA. Our utilization of glass box machine learning provides a novel risk quantification for THA with detail and nuance that may help optimize future procedures, particularly as the demographics of patients undergoing THA continues to encompass a broader range of ages.

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Table 1. Cohort characteristics.

Variable*	N=105336
Age	65.0 [58.0, 73.0]
Sex	
Female	56977 (54.1%)
Race	
White	95158 (90.3%)
Black	6954 (6.60%)
Other	3142 (2.98%)
Missing	82 (0.1%)
Discharge location	
Home or HHC	82262 (78.1%)
Post-acute care	22200 (21.1%)
Other	870 (0.83%)
Insurance	
Commercial	44834 (42.6%)
Government	686 (0.7%)
Medicaid	4745 (4.5%)
Medicare	54334 (51.6%)
Unknown/uninsured	737 (0.7%)
Hypertension	65135 (61.8%)
Obesity	22363 (21.2%)
Elixhauser comorbidity index	0 [0, 2]

* Data presented as N (%) or Median [IQR].
HHC, health home care.

Figure 1. Partial dependence of age (years) on (A) 90-day readmission, (B) 90-day mortality, (C) 1-year revision, and (D) length of stay. Y-axis score in log scale. Vertical lines demonstrate where risk score is equal to 0, and show the average contribution of age to risk.

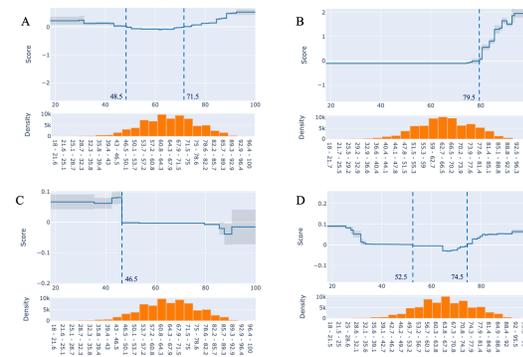


Figure 2: Partial dependency plot of (A) 90-day readmission, (B) 90-day mortality, (C) 1-year revision, and (D) LOS and the interaction of age (years, x-axis) with predictive factors (y-axis). Predictive factors include: (A1) discharge location, (A2) insurance, (B1) discharge location, (B2) Elixhauser Comorbidity index, (B3) sex, (B4) hypertension, (C1) discharge location, (C2) insurance, (C3) Elixhauser Comorbidity index, (C4) hypertension, (D1) discharge location, and (D2) insurance. Color corresponds to the mean absolute score, with darker color demonstrating more negative score and lighter color demonstrating more positive score (see right-hand axis).

