Using Machine Learning Methods to Predict Reverse Total Shoulder Arthroplasty Patient Outcomes

Sachin Shankar, MS[1] (Medical Student), Luke Maymir, MS[1], Logan Lake, BS[2], Isaac Hale, BS[2], Paul McMillan, MD[2], Kim Hasselfeld, MS[2], Thomas Talavage, PhD[3], Brian Grawe, MD[2] (PI)

[1]University of Cincinnati College of Medicine, Cincinnati, OH
[2]University of Cincinnati Department of Orthopedic Surgery and Sports Medicine, Cincinnati, OH
[3]University of Cincinnati Department of Biomedical Engineering, Cincinnati, OH

Introduction: Reverse Total Shoulder Arthroplasty (rTSA) is a type of shoulder replacement surgery commonly performed by orthopaedic surgeons. In rTSA, the prosthetic ball is placed on the socket side of the shoulder joint while the prosthetic socket is placed on the arm side of the shoulder joint supported by a metal stem in the humerus. rTSA is an increasingly common procedure, as it made up almost 70% of all shoulder arthroplasty cases in 2020. Hence, it is important to develop a strong understanding of how various patient predictive factors can impact rTSA post-op outcomes, as previous studies have only examine a limited number of post-rTSA outcomes and they do not implement any Machine Learning (ML) based prediction approaches. This project seeks to develop a ML pipeline that identifies predictive factors of rTSA post-op outcomes when assessing any given patient’s need for rTSA.

Methods: Current Procedural Terminology codes were used to retrospectively identify patients who underwent a rTSA procedure from 2010 to 2022 at UC Medical Center. Patient data collected included Demographics, Surgical and Physical Exam Details, and American Shoulder and Elbow Surgeons (ASES) metrics both at baseline procedure and 6-month follow-up. The primary outcome assessed was the change in patient ASES Scores (a standardized method of assessing shoulder function) over the 6-month time period following surgery. 40 different predictors (22 continuous, 13 binary, 5 categorical) of this outcome were identified. 80% of the dataset was randomly selected as a training dataset set whilst the remaining 20% of the dataset was designated as the test dataset. Several different ML model architectures were developed and trained, including Multiple Linear Regression with and without LASSO regularization as well as Support Vector Machine Regression (SVM) with Linear, Gaussian, and Radial Basis Function kernels. Each of these models performances were then assessed and compared.

Results: A total of 109 patients had their data used for the development of the ML model. Each model’s regression performance was assessed via their root mean square error or RMSE (which has units of ASES points) computed based on the test dataset. The Multiple Linear Regression model without regularization had a RMSE = 26.9 and adding LASSO resulted in a reduction of the RMSE down to 14.3. The SVM model with a linear kernel had a RMSE = 28.8, while using a Gaussian and Radial Basis Function kernel both resulted in a slightly lower RMSE = 28.0.

Conclusion: The Multiple Linear Regression Model with LASSO performed significantly better than all other models in this study. This study presents the first attempt at using ML as a predictive tool to assess rTSA outcomes, and thus further validation is warranted before these technologies can be incorporated into orthopaedic clinical practice.

Presenting Author Contact Information:
Sachin Shankar
shankasc@mail.uc.edu
+1-937-694-0759
ORCID: https://orcid.org/0000-0002-8124-1433

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Introduction

- Reverse Total Shoulder Arthroplasty (rTSA) is a shoulder joint replacement surgery in which the prosthetic ball is placed on the socket side of the joint while the prosthetic socket is placed on the arm side of the joint, supported by a metal stem in the humerus
  - i.e. prosthesis is in reverse of the naturally occurring ball and socket locations
- rTSA is an increasingly common procedure in the US, making up 70% (~20,000 cases) of all shoulder arthroplasty cases as of 2020
- rTSA is indicated for several common shoulder pathologies, including osteoarthritis, sports injuries, or trauma
- It's clinically important to develop a strong understanding of how various patient predictive factors can impact post-op rTSA outcomes:
  - Previous studies have only examined a very limited number of patient factors and their role on a limited number of post-rTSA outcomes
  - No Previous study has implemented any Machine Learning (ML) based rTSA prediction approaches

Purpose

- Develop a ML pipeline that can pre-operatively predict any given individual patient's change in shoulder function (measured by ASES Score) 6 months following rTSA surgery
  - Help orthopedic surgeons to identify relevant factors when assessing patients on whether surgery would be beneficial

Methods

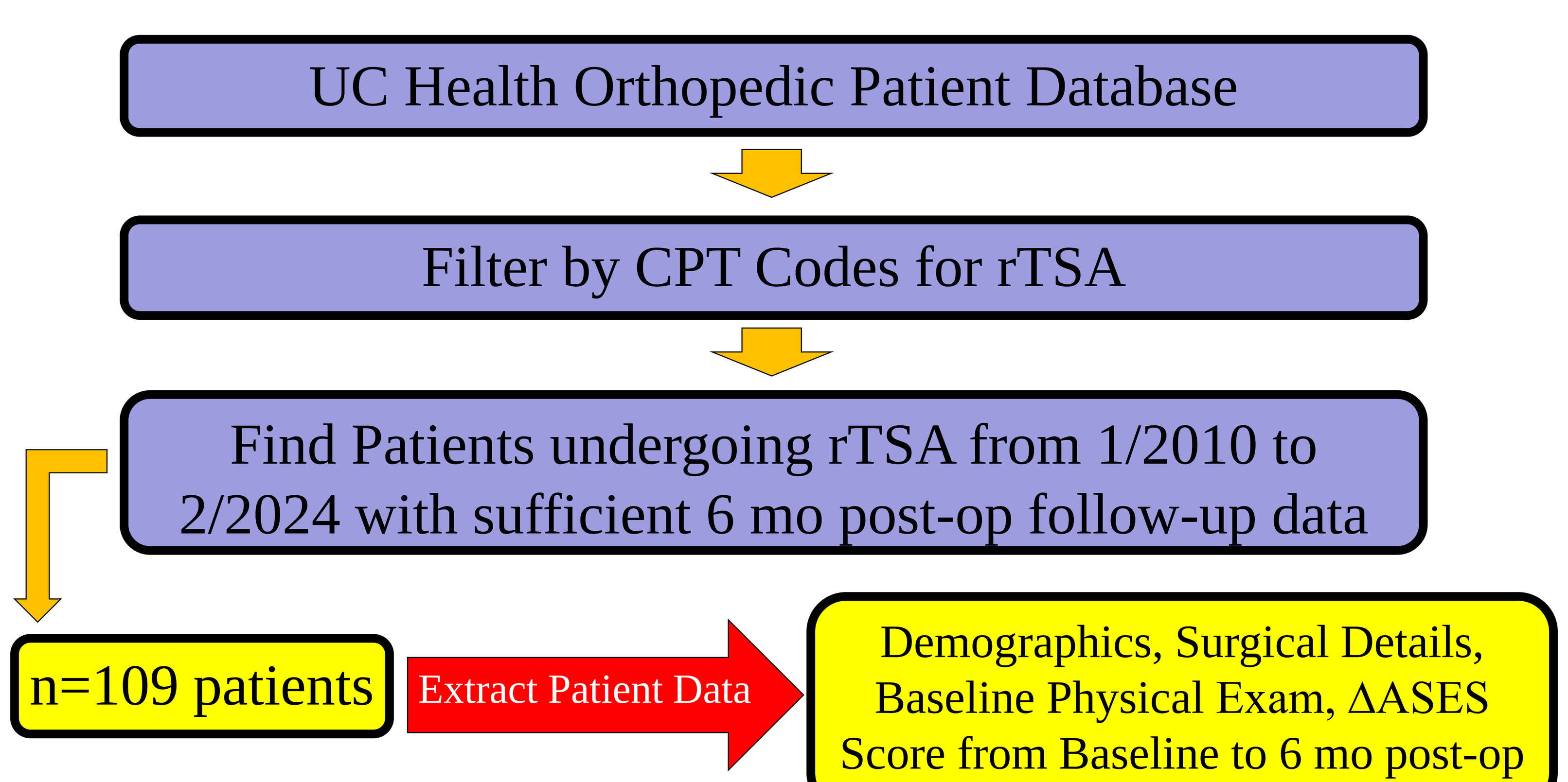

Figure 1. Data Acquisition Workflow

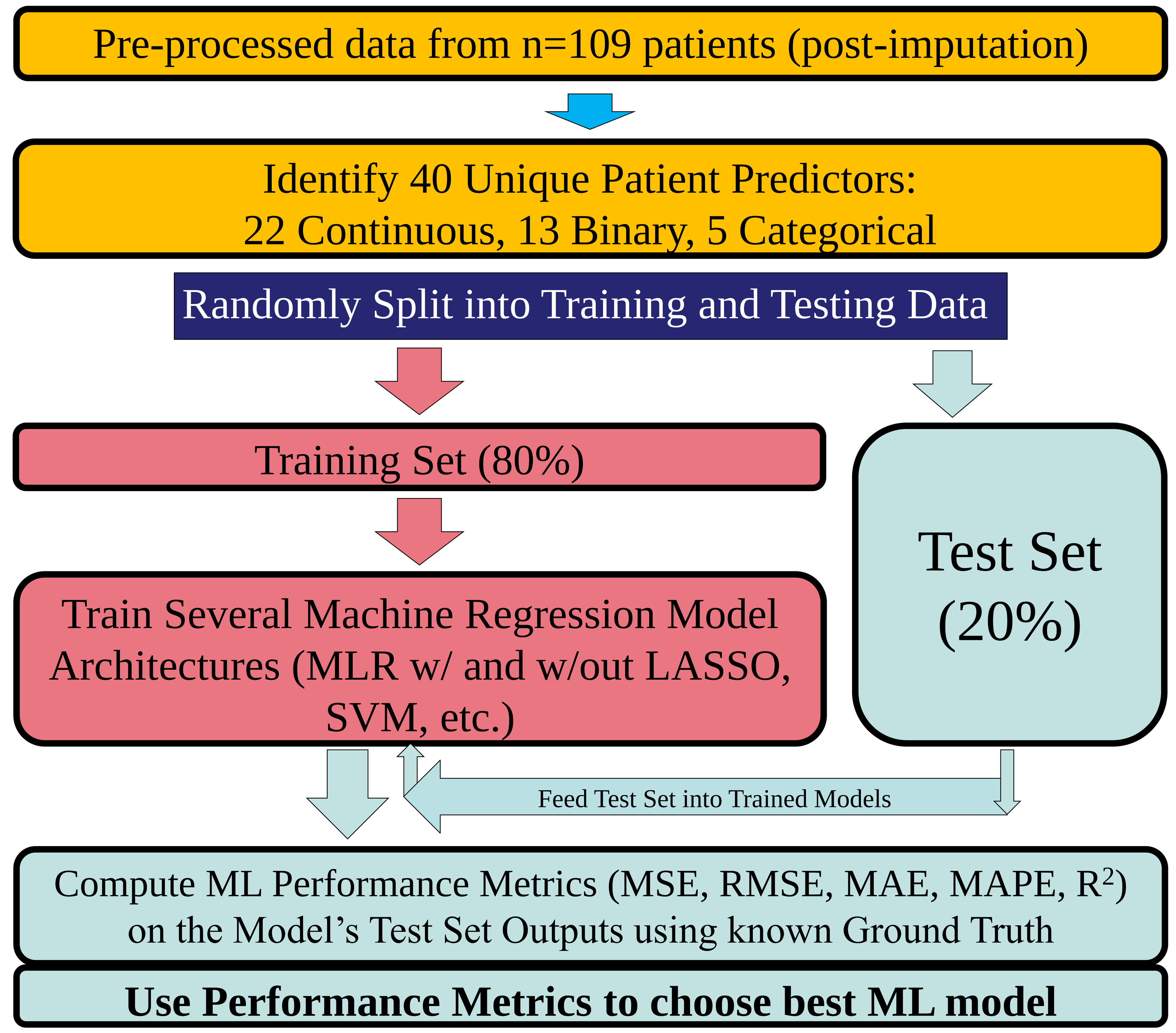

Figure 2. Machine Learning Code Pipeline

Results

Table 1. Performance Metrics of the Several ML Regression-Based Architectures Trained

ML Model Name	Performance Metric Name				
	MSE	RMSE	MAE	MAPE (%)	R^2
MLR	457	21.4	17.1	95	-0.10
MLR with LASSO	**203**	**14.3**	**11.7**	77	**0.70**
MLR with Ridge	240	15.5	13.3	98	0.64
MLR with Elastic Net (weight=0.5)	219	14.8	12.7	88	0.67
SVM Linear Kernel	419	20.5	16.1	90	0.01
SVM RBF Kernel	367	19.2	15.1	80	-
Decision Tree (Fine)	374	19.3	15.5	78	-
Regression Tree Ensemble (Boosted)	404	20.1	15.9	**69**	-
Optimizable Gaussian Process	364	19.1	15.1	79	-
Neural Network (bilayer, feedforward fully connected)	2945	54.3	38.9	125	-

MLR with LASSO has best performance

MSE = Mean Squared Error, RMSE = Root Mean Squared Error, MAE = Mean Absolute Error, MAPE = Mean Absolute Percent Error, R^2 = Coeff of Determination
MLR = Multiple Linear Regression, LASSO = L1 Regularization , SVM = Support Vector Machine Regression, RBF = Radial Basis Function Kernel

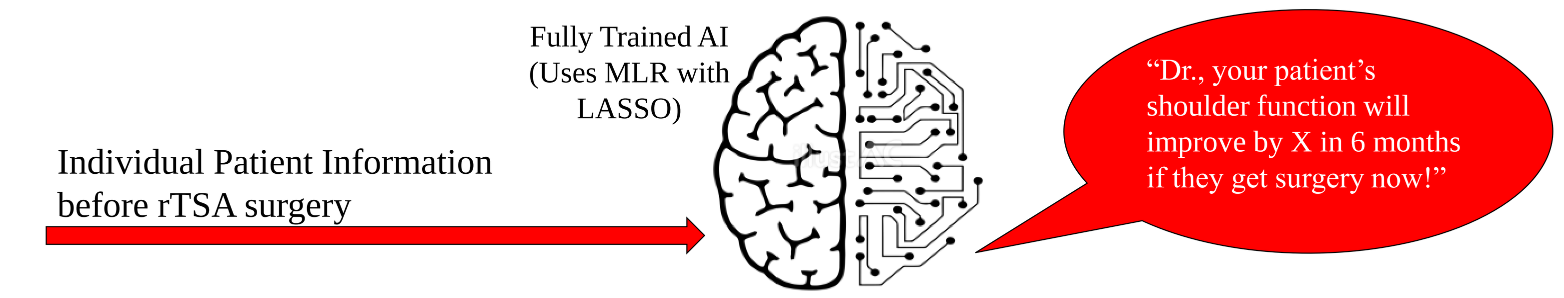

Figure 3. Overview of this AI Tool's Utility in Clinical Practice for Physicians

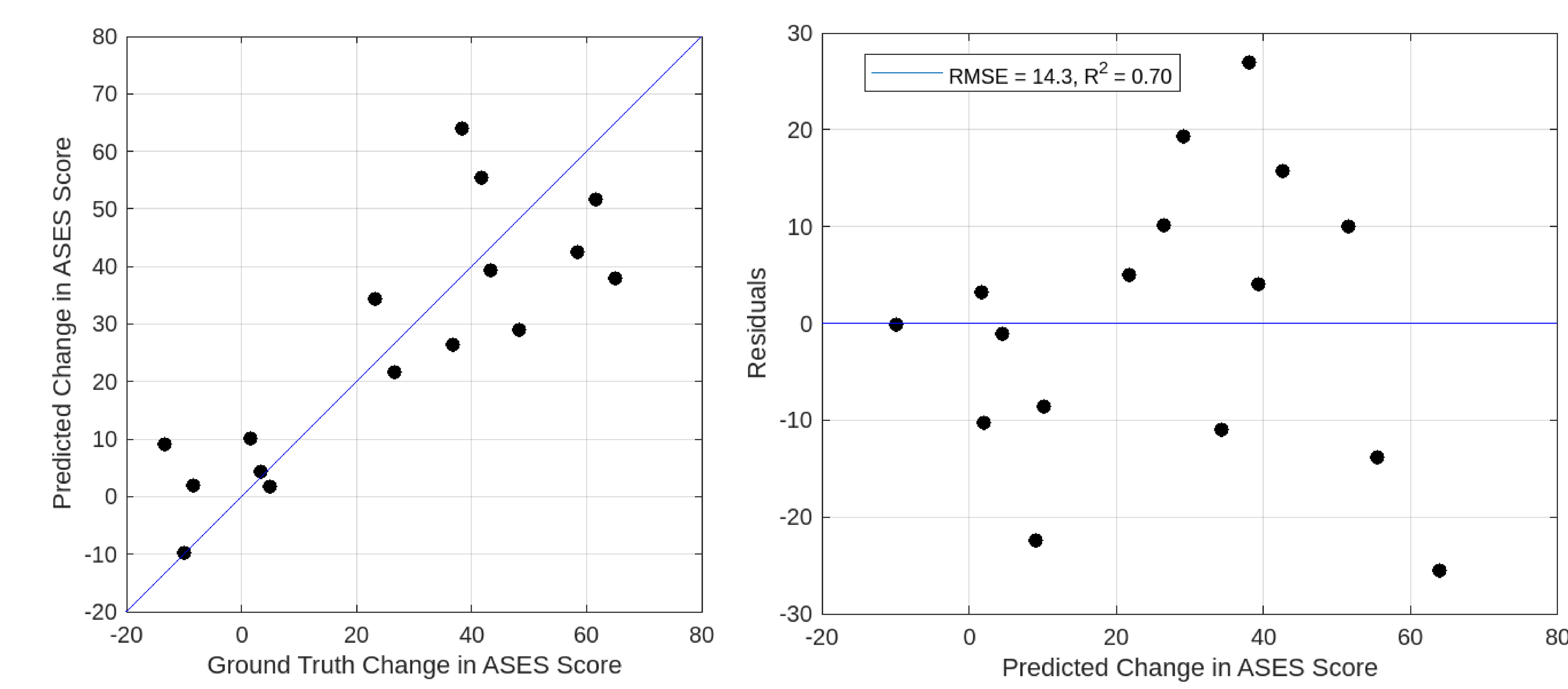

Figure 4. MLR with LASSO Predicted vs. Actual ΔASES (left) and Residual Plot (right) in Sample Test Set

Discussion

- Deep Learning (neural network) approach performed the worst
- Simplest model (MLR) didn't perform well (R^2<0), but performance **drastically** improves when adding regularization
  - i.e. simpler algorithms worked better
- All other models had similar levels of intermediate performance
- No patterns in residual plot (desired)
- Although some of the metrics may seem misleadingly high (ex. MAPE), a balance between model overfitting vs. generalizability needs to be made (bias–variance tradeoff)

Limitations:

- Small training sample size
- Next Step: This represents the first attempts at ML predicting rTSA outcomes, and further validation is needed before such AI/ML tools can be used in clinical practice

Conclusions:

- Demonstrated the potential utility of AI/ML in orthopedic surgery
- Expanded the number of post-rTSA outcomes (i.e. use cases) that can be predicted, yielding a more comprehensive understanding of the effect of patient features on surgical outcomes

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