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Using Patient Demographics and Statistical Modeling to Predict Knee Tibia Component Sizing in Total Knee Arthroplasty

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ABSTRACT

Background: Preoperative planning is important to achieve successful implantation in primary total knee arthroplasty (TKA). However, traditional TKA templating techniques are not accurate enough to predict the component size to a very close range.

Methods: With the goal of developing a general predictive statistical model using patient demographic information, ordinal logistic regression was applied to build a proportional odds model to predict the tibia component size. The study retrospectively collected the data of 1992 primary Persona Knee System TKA procedures. Of them, 199 procedures were randomly selected as testing data and the rest of the data were randomly partitioned between model training data and model evaluation data with a ratio of 7:3. Different models were trained and evaluated on the training and validation data sets after data exploration.

Results: The final model had patient gender, age, weight, and height as independent variables and predicted the tibia size within 1 size difference 96% of the time on the validation data, 94% of the time on the testing data, and 92% on a prospective cadaver data set.

Conclusion: The study results indicated the statistical model built by ordinal logistic regression can increase the accuracy of tibia sizing information for Persona Knee preoperative templating. This research shows statistical modeling may be used with radiographs to dramatically enhance the templating accuracy, efficiency, and quality. In general, this methodology can be applied to other TKA products when the data are applicable.

Preoperative planning is important to achieve successful implantation in primary total knee arthroplasty (TKA). This will improve the preparedness of the surgeon and their support staff while decreasing the likelihood of an adverse event [1]. One key aspect of preoperative planning is orthopedic templating.

Orthopedic templating is the process of using acetate or digital templates to estimate the prosthesis size to be used in surgery [2]. Today, most surgeons import the patient's digital X-rays into a commercially available templating application that enables the surgeon to overlay the product-specific implant outlines over the X-ray of the bone [2]. The surgeon can evaluate numerous components and sizes until the best fit option is selected. The ability to accurately predict the correct prosthesis size is dependent upon receiving a true anteroposterior and lateral X-ray without patient rotation. In addition, accuracy can be influenced by the location of the X-ray calibration marker in the field of view [3]. The benefits to accurate templating may include decreasing total procedure time, sterilization costs, and time and reducing the on-site inventory required at a hospital or surgical center [1]. This article explores the possibility of building a statistical model to increase the accuracy of templating for knee tibia component in primary TKA procedure.

Previous articles have explored the accuracy of templating using digital images [4–11] where templating success ranged from about 50% to 75%. Some research has explored the relationship of patient demographics to the size of TKA components. One article demonstrated that demographic factors such as gender, height, weight, and body mass index (BMI) can be used to predict reasonably

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accurate component sizes [12]. In addition to patient gender, height, weight, and BMI, patient ethnicity has also been shown to have an effect on component size [13] along with bone morphotypes [14,15].

The primary research goal is to develop a statistical model to accurately predict tibia component size based on individual patient demographics of gender, height, weight, BMI, and age. The developed statistical model can supplement digital images currently used in templating to dramatically improve the accuracy. A surgeon can use the model to get a predicted tibia component size with high accuracy.

A secondary goal is to assess the effect of the individual surgeon on the selected component size because the surgeon ultimately selects the size that is implanted into the patient. Although it is known that patient demographics and patient bone morphology have a direct relationship to component size, a few studies have shown that surgeon preference and operative style may also have an influence on sizing the component to a patient [6,8,9].

Materials and Methods

With the goal of obtaining well-represented study population features, 1992 primary Persona Knee System patients' data were retrospectively identified across 7 Zimmer Biomet Inc—sponsored clinical studies [16]. Each individual record in the data included patient demographic data (gender, weight, height, etc.), implanted device, implant configuration, component size, and surgeon identification. The 1992 primary procedures, including 1220 (61%) female cases and 772 (39%) male cases, had an average age of 64.5 years, average weight of 199.9 lb, and average height of 168.4 cm (Table 1). The implanted Persona tibia component sizes in this study were C, D, E, F, G, H, and J, where C was the smallest and J was the largest. All of the patients had either Persona posterior-stabilized femur or Persona cruciate-retaining (CR) femur.

Following best practices in developing statistical predicting models [17], 199 data records were selected by simple random sampling and set aside for model performance hold-out testing data. The rest of the data were randomly partitioned into training data (1259 cases) and validation data (534 cases). The training set is used to fit and tune the potential statistical models and the validation data set is used to assess the accuracy, parameter estimate errors, and score data fit statistics of the potential models for the final model selection. Lastly, after a model has been refined and selected, the hold-out testing data set is used to test the performance of the final model in a "new data" setting.

Considering the tibia component size data as ordinal scale in ascending order from C to J, a proportional odds model was built by ordinal logistic regression. A proportional odds model is an effective and efficient statistical regression model that can be used to predict ordered data. In this case, the ordered data are the tibia component sizes. The model was developed and implemented using Statistical Analysis Software (SAS) 9.4 TS Level 1M3.

Contingency tables were used to explore the data distribution. Cumulative logit plots and score tests were applied to verify the proportional odds model assumption. For the model building, forward selection method was used to select variables for the model with significant level of 0.01 for a variable to enter the model. Ordinal logistic regression was conducted to select the significant variables and started with a full factorial model including variables of gender, age, weight, and height and all of their interactions. The models that used different subsets of demographic features (including BMI and ethnicity) and performing surgeon as independent variables were also developed by the same method on the training data set.

Type III analyses of effects, odds ratio, and its 95% confidence interval were used to evaluate and confirm the selected variables' influence on the tibia component size. Using the model, the patients' probabilities for each tibia component size from C to J can be calculated and the size with the highest probability will be the predicted tibia component size for the patient.

All of the built models were scored and evaluated by the validation data set. Then, the selected final model was scored on the testing data set for the model performance testing. To estimate the model's robustness to the variation of the data and to determine an average accuracy rate, unrestricted random sampling was used to generate 1000 validation samples and 1000 testing samples. The average accuracy over the 1000 validation samples was evaluated for each of the trained models. The final selected model's average accuracy rate over 1000 testing samples was then calculated.

Table 1
Whole Cohort Patient Demographic Data.

Variable	Mean	SD	Range
Age	64.5	8.9	19.0-90.0
Weight (lb)	199.9	40.3	105.0-299.0
Height (cm)	168.4	10.1	147.0-198.1

SD, standard deviation.

Table 2
Training Set Patient Demographic Data.

Variable	Mean	SD	Range
Age	64.6	9.0	19.0-90.0
Weight (lb)	199.1	39.8	105.0-299.0
Height (cm)	168.5	10.0	147.0-198.1

SD, standard deviation.

Results

Among the 1259 procedures in the training data set, 766 (61%) were from female patients and 493 (39%) were from male patients. These patients had an average age of 64.6 years, average weight of 199.1 lb, and average height of 168.5 cm (Table 2).

Table 3
Implanted Size vs Predicted Size Distribution for Validation Data Set.

Actual Implanted TBP Size		Predicted TBP Size	
Size	n/N (%)	Size	n/N (%)
C	49/534 (9.18)	C	11/49 (22.45)
		D	37/49 (75.51)
		E	1/49 (2.04)
D	132/534 (24.72)	C	5/132 (3.79)
		D	88/132 (66.67)
		E	39/132 (29.55)
E	150/534 (28.09)	C	4/150 (2.67)
		D	41/150 (27.33)
		E	80/150 (53.33)
		F	18/150 (12)
		G	7/150 (4.67)
F	91/534 (17.04)	D	5/91 (5.49)
		E	25/91 (27.47)
		F	38/91 (41.76)
		G	23/91 (25.27)
G	87/534 (16.29)	E	3/87 (3.45)
		F	18/87 (20.69)
		G	64/87 (73.56)
		H	2/87 (2.3)
H	23/534 (4.31)	F	1/23 (4.35)
		G	18/23 (78.26)
		H	4/23 (17.39)
J	2/534 (0.37)	G	1/2 (50)
		H	1/2 (50)

TBP, tibia base plate.