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Original Research

# Patient Demographics and Anthropometric Measurements Predict Tibial and Femoral Component Sizing in Total Knee Arthroplasty

Dominic Marino, DO [a, b, c, *], Jay Patel, DO [a, b, c], John M. Popovich Jr., PhD, DPT [c, d], Jason Cochran, DO [a, b, c]

[a] *Department of Orthopedic Surgery, McLaren-Greater Lansing Hospital, Lansing, MI, USA*
[b] *Department of Osteopathic Surgical Specialties, Michigan State University, East Lansing, MI, USA*
[c] *Department of Orthopedic Surgery, Sparrow Hospital, Lansing, MI, USA*
[d] *Michigan State University Center for Orthopedic Research, East Lansing, MI, USA*

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## A B S T R A C T

*Background:* Accurate sizing is critical for the overall success of a total knee arthroplasty (TKA). This study's primary purpose was to investigate the ability to predict the tibial and femoral component size in a single implant system from patient demographics and anthropometric data. A secondary goal was to compare the predicted tibial and femoral component sizes from our statistical model with a previously validated electronic application used to predict the implant size.

*Methods:* A consecutive series of 484 patients undergoing a primary TKA at a single institution was reviewed. Data on height, weight, body mass index, sex, age, and component size were collected. A proportional odds model was developed to predict tibial and femoral component sizes. The relationship between the proportional odds model predictions was also compared with the component sizes determined by the Arthroplasty Size Predictor electronic application.

*Results:* Weight, height, and sex predicted the implanted component size with an accuracy of 54.0% ($n = 247/484$) for the tibia and 51.1% ($n = 231/484$) for the femur. The accuracy improved to 94.4% ($n = 457/484$) for the tibia and 93.4% ($n = 452/484$) for the femur within ±1 component size. Our data are highly correlated to the Arthroplasty Size Predictor for the predicted tibial component size ($\rho = 0.91$, $P < .001$) and femoral component size ($\rho = 0.89$, $P < .001$).

*Conclusions:* Our novel templating model may improve operative efficiency for a single TKA system. Our findings have a high concordance with a widely available electronic application used to predict implant sizes for a variety of TKA systems.

## Introduction

Total knee arthroplasty (TKA) surgery has been a successful treatment option for many suffering from debilitating arthritis [1]. Advances in technology have allowed for a more extensive inventory of implant sizes and improved anatomic fit, resulting in a higher implant survival rate and improved patient outcomes [1,2]. A well-balanced knee is crucial to the survival and function of an arthroplasty [3]. Malalignment and malposition are a common reason for revision of TKAs. Varus or valgus malalignment in TKA can lead to increased polyethylene wear, ligament instability, and loosening, resulting in the need for revision surgery [3]. Accurate sizing is critical for overall alignment and proper balancing of TKA. Oversizing can result in knee stiffness and anterior knee pain. Undersizing can lead to the notching of the anterior femoral cortex [1].

Attempts to improve TKA fit have included preoperative templating, patient-specific implants, and robot-assisted surgery [4-6]. Digital templating has not proven to be useful in TKA as it is in the hip arthroplasty literature, as studies have shown controversial results. Digital templating can correctly predict the implant size within 2 sizes of the final component. Of all, 98.5% of preoperative templating was within one size of the final implant for TKA [4]. Conversely, a study by Ooka et al showed preoperative templating to be an unreliable tool for TKA although results improved when considering an error margin of ± one implant size [4-6]. Templating

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* Corresponding author. McLaren-Greater Lansing Hospital, 2727 South Pennsylvania Avenue, Lansing MI, 48910, USA. Tel.: +1 518 744 9800.

*E-mail address:* Dominic.marino@mclaren.org

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was accurate only 28.21% of the time when using anteroposterior and 35.90% of the time using lateral radiographs for femoral components. These results did not show significant improvement for tibial components showing 37.61% and 47.01% accuracy for anteroposterior and lateral views, respectively, demonstrating poor results with radiographic templating overall [7]. Templating is also time-consuming, costly, and cumbersome. Patient-specific cutting blocks also entail substantial cost to the patient and the hospital [8].

Previous studies have used patient demographic information to predict TKA component sizes across multiple knee arthroplasty systems [1,9,10]. Many of these studies are conducted using a single knee arthroplasty system or unequal distribution of knee arthroplasty systems. For example, Rehman et al. demonstrated a correlation between the shoe size and TKA components, as well as the height and TKA components [1]; however, this study included 3 different implants (Medial Rotation Knee, Vanguard, and Press-Fit Condylar) and did not include the TKA system used in our study [1]. van Egmond et al noted an agreement of femoral components of 94% and tibial components of 86% within ±1 size [11]. Miller and Purtill also analyzed only a single system; however, it only included 123 patients [12]. Ren et al. used ordinal regression to analyze 199 knees and were able to correctly template the tibial size in 94% of patients within ±1 size using a competitor knee system [10]. Sershon et al demonstrated the ability to predict the final implants within ±1 size using patient demographics across multiple TKA implant systems. They were able to predict the tibial component size in 87% (n = 412/474) and 76% (n = 360/474) of femoral components [9]. This study has been further validated by the same group, and an electronic application has been developed for clinical use [13]. Considering the relatively small number (n = 21) of the systems chosen for our study included in this validation study by the same group leaves some questions regarding the application of their study to multiple TKA systems and at other institutions.

Considering our institution performs a high volume of TKA, the primary purpose of this study was to investigate the ability to predict the tibial and femoral component size in a single implant system from patient characteristics, such as sex, weight, and height. A secondary goal was to compare the predicted tibial and femoral component sizes from our statistical model with the electronic application designed by Sershon (Arthroplasty Size Predictor, Apple App Store, 2017) [13]. Being able to accurately predict component sizes for those undergoing primary TKA surgery may improve operating room efficiency, decrease the total operative time, decrease operative waste, and decrease facility cost.

## Material and methods

This was a retrospective analysis of patients undergoing primary TKA surgery at a single institution performed by a single fellowship-trained arthroplasty surgeon using the Stryker Triathlon total knee system (Stryker, Kalamazoo, MI). From July 2016 to June 2018, 517 patients were identified in the electronic medical record (EMR) by information technology inquiry at our institution. The system used in this study has sizes ranging from size 1 (smallest) to size 8 (largest). The femoral and tibial sizes increase proportionally by 3 millimeters in the anteroposterior and mediolateral dimensions from size 1 to size 7 and by 4 millimeters from size 7 to size 8. The inclusion criteria for the study included any patient older than 18 years who had undergone primary TKA. Patients who had undergone arthroplasty for fracture, revision TKA, conversion from a unicompartmental arthroplasty, and primary unicompartmental knee arthroplasty and patients with incomplete data were excluded from the study (Fig. 1). The following information was collected from the EMR for each patient: height, weight, body mass index (BMI), sex, and age on the date of the surgery. An operative report generated on the day of surgery was accessed by the EMR and used to document the final tibial and femoral component size implanted. The tibial bearing size was not collected. This study was determined to be exempt by our institutional review board.

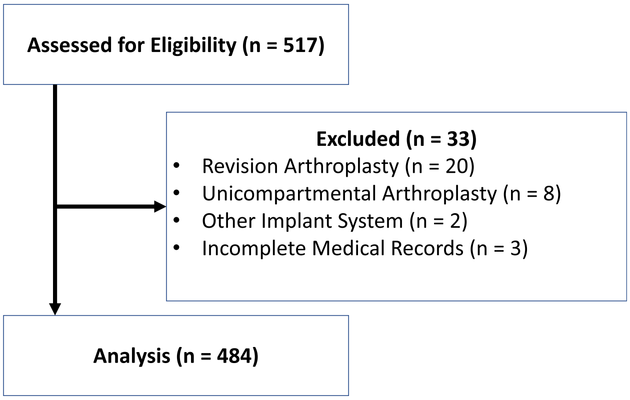

**Figure 1.** Flow diagram of patients included in the study.

To compare our results to the electronic application developed by Sershon et al., we downloaded the application (Arthroplasty Size Predictor, Apple App Store, 2017) and entered our data into the application [13]. For each patient, we inputted the following data: (1) company (Stryker), (2) model (Triathlon), (3) sex (male or female), (4) height (cm), and (5) weight (kg). After these data were entered, femoral and tibial predicted component sizes from the electronic application were recorded.

### *Statistical analysis*

Demographic data are presented as means, standard deviations, and percentiles. To predict tibial and femoral component sizes, cumulative odds ordinal logistic regression with proportional odds was used, similar to that reported by Ren et al [10]. This analysis was chosen considering the components used are based on an ordinal scale (ie, #1-#8). Model performance was evaluated by the ability (% accuracy) to predict the component size under the following conditions: (1) as implanted and (2) ± 1 from the size implanted. In addition, we compared the predicted results of our statistical model with the predicted values from the Arthroplasty Size Predictor electronic application. Spearman's $\rho$ was also used to determine the relationship between predicted results of the ordinal logistic regression models and Arthroplasty Size Predictor. All statistical analyses were conducted using SPSS (version 25, IBM Corp., NY), with statistical significance set at $P \le .05$.

## Results

Of the 517 patients identified as part of the retrospective review, 33 were eliminated after accounting for our exclusion criteria (Fig. 1), resulting in an analysis of 484 patients who underwent primary TKA. Of the 484 patients who underwent TKA, 61.4% (n = 297/484) of the subjects were women (age = 66.3 ± 9.0 years, height = 1.62 ± 0.1 m, weight = 87.8 ± 17.3 kg, BMI = 33.3 ± 6.1 kg/m$^2$) and 38.6% (n = 187/484) were men (age = 66.9 ± 8.5 years, height = 1.79 ± 0.1 m, weight = 106.1 ± 19.0 kg, BMI = 33.2 ± 5.5 kg/m$^2$). The most common femur and tibia size implanted for women was a size 4 and for men was a size 6 (Table 1). The range of components implanted in our study is size 1 to size 8 for the femur and size 1 to size 7 for the tibia (Table 2).

For the tibial component size, the overall model (age, height, weight, sex) predicted the implanted component size with an accuracy of 50.6% (n = 245/484). When increasing the tolerance of prediction to be within ±1 component size, the accuracy improved to 94.4% (n = 457/484). However, age was an insignificant factor in

**Table 1**
Frequency of implanted tibial and femoral component sizes.

| Component size | Tibial component | | | Femoral component | | |
|---|---|---|---|---|---|---|
| | Female | Male | Total | Female | Male | Total |
| 1 | 5 | 0 | 5 | 5 | 0 | 5 |
| 2 | 19 | 0 | 19 | 22 | 0 | 22 |
| 3 | 106 | 2 | 108 | 112 | 4 | 116 |
| 4 | **125** | 13 | **138** | **115** | 21 | **136** |
| 5 | 31 | 52 | 83 | 31 | 60 | 91 |
| 6 | 8 | **82** | 90 | 9 | **74** | 103 |
| 7 | 3 | 38 | 41 | 3 | 27 | 30 |
| 8 | 0 | 0 | 0 | 0 | 1 | 1 |

Bold indicates most frequently used (mode).

the model ($P = .49$) and was removed; thus, the resulting model included height, weight, and sex. When height, weight, and sex were included, the implanted tibial component size was predicted with an accuracy of 54.0% (n = 247/484) and increased to 94.4% within ±1 component size. The resulting prediction model for the tibial component size can be expressed by the following equation:

$$Pcumi\,\frac{1}{1+\exp(-(Bi-(0.022*Weight)+(0.157*Height)+(-2.127*Sex)))}$$

where P*cumi* is the predicted cumulative probability for the tibial component size $i$ ($i = [1,2,3,4,5,6]$ and B$i$ is the weighted coefficient for each tibial component size $i$: $B_1 = 20.049$, $B_2 = 22.162$, $B_3 = 24.895$, $B_4 = 27.461$, $B_5 = 29.544$, $B_6 = 31.896$. Weight is entered in kg, Height is entered in cm, and Sex is coded as 0 = female and 1 = male. The predicted probability for each size is calculated as follows: $P_1 = Pcum_1$; $P_2 = Pcum_2\text{-}P_1$; $P_3 = Pcum_3\text{-}P_1\text{-}P_2$; $P_4 = Pcum_4\text{-}P_1\text{-}P_2\text{-}P_3$; $P_5 = Pcum_5\text{-}P_1\text{-}P_2\text{-}P_3\text{-}P_4$; $P_6 = Pcum_6\text{-}P_1\text{-}P_2\text{-}P_3\text{-}P_4\text{-}P_5$; and $P_7 = 1 - Pcum_6$. These predicted probabilities are ranked, and the one with the highest predicted probability results in the model predicted component size. Model predictions for each tibial component size are presented in Table 2.

The results were similar for the femoral component size, where the overall model (inclusive of age, height, weight, sex) predicted the implanted component size with an accuracy of 47.5% (n = 230/484). When increasing the tolerance of prediction to be within ±1 component size, the accuracy improved to 93.6% (n = 453/484). Age was also insignificant ($P = .94$), which resulted in removal and the subsequent model consisting of height, weight, and sex. When height, weight, and sex were included, the implanted femoral component size was predicted with an accuracy of 51.1% (n = 231/484) and increased to 93.4% (n = 452/484) within ±1 component size. The resulting prediction model for the femoral component size can be expressed by the following equation:

$$Pcumj\,\frac{1}{1+\exp(-(Bj-(0.022*Weight)+(0.142*Height)+(-1.608*Sex)))}$$

where P*cumj* is the predicted cumulative probability for the femoral component size $j$ ($j = [1,2,3,4,5,6,7]$ and B$j$ is the weighted coefficient for each femoral component size $j$: $B_1 = 18.402$, $B_2 = 20.584$, $B_3 = 23.246$, $B_4 = 25.582$, $B_5 = 27.536$, $B_6 = 29.810$, $B_7 = 33.627$. Weight is entered in kg, Height is entered in cm, and Sex is coded as 0 = female and 1 = male. The predicted probability for

**Table 2**
Performance (percentage correctly predicted) as a function of the component size for the tibia and femur.

| Tibia | Femur | Component size | Tibia | | Femur | |
|---|---|---|---|---|---|---|
| Number of cases | Number of cases | | As implanted (%) | ±1 size (%) | As implanted (%) | ±1 size (%) |
| 5 | 5 | 1 | 0.0 | 60.0 | 0.0 | 20.0 |
| 19 | 22 | 2 | 15.8 | 89.5 | 0.0 | 54.5 |
| 108 | 116 | 3 | 85.2 | 98.1 | 32.8 | 96.6 |
| 138 | 136 | 4 | 37.7 | 94.2 | 70.6 | 93.4 |
| 83 | 91 | 5 | 14.5 | 79.5 | 4.4 | 94.5 |
| 90 | 83 | 6 | 80.0 | 91.1 | 86.7 | 92.8 |
| 41 | 30 | 7 | 19.5 | 90.2 | 10.0 | 86.7 |
| 0 | 1 | 8 | None | None | 0.0 | 0.0 |

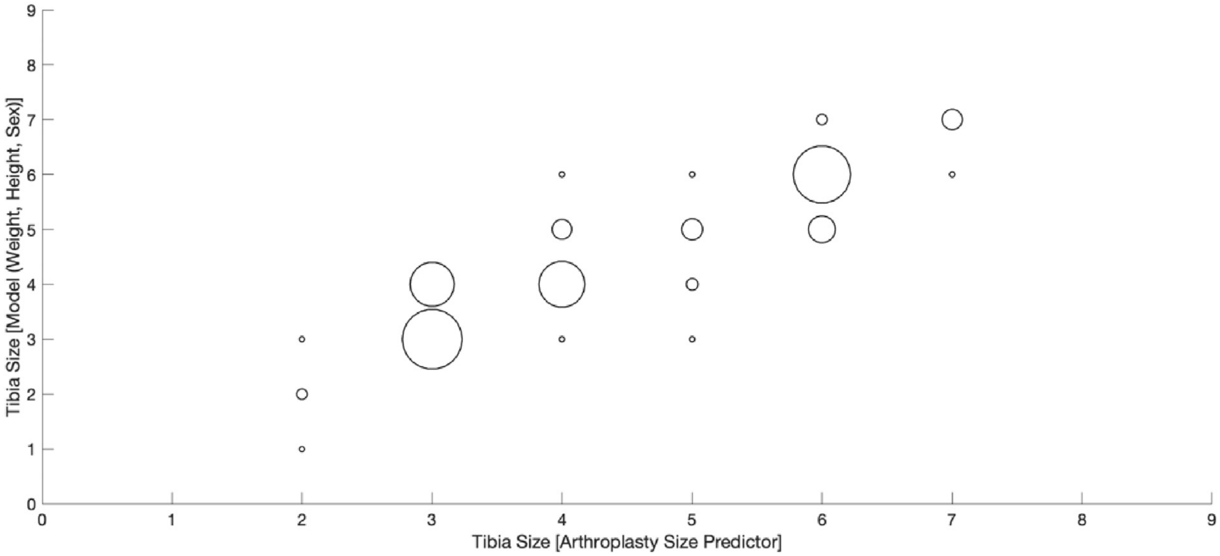

**Figure 2.** Relationship between ordinal regression model–predicted tibial component size and Arthroplasty Size Predictor tibial component size results. The size of the bubble corresponds to the number of cases (ie, larger diameter = more cases).

each size is calculated as follows: $P_1 = Pcum_1$; $P_2 = Pcum_2\text{-}P_1$; $P_3 = Pcum_3\text{-}P_1\text{-}P_2$; $P_4 = Pcum_4\text{-}P_1\text{-}P_2\text{-}P_3$; $P_5 = Pcum_5\text{-}P_1\text{-}P_2\text{-}P_3\text{-}P_4$; $P_6 = Pcum_6\text{-}P_1\text{-}P_2\text{-}P_3\text{-}P_4\text{-}P_5$; $P_7 = Pcum_7\text{-}P_1\text{-}P_2\text{-}P3\text{-}P_4\text{-}P_5\text{-}P_6$; and $P_8 = 1 - Pcum_7$. As with the tibial prediction calculations, these predicted probabilities are ranked and the one with the highest predicted probability results in the model-predicted femoral component size. Model predictions for each femoral component size are presented in Table 2.

When our data were compared with the Arthroplasty Size Predictor [13], the electronic application was able to predict implanted tibial and femoral component sizes in 49% (n = 239/484) and 44% (n = 213/484) of tibias and femurs, respectively (Table 2). When increasing the tolerance to ±1 component size, the electronic application's prediction improved to 91% (n = 441/484) for both tibias and femurs. These results from the Arthroplasty Size Predictor were highly correlated to the predicted tibial component size ($\rho = 0.91$, $P < .001$; Fig. 2) and femoral component size ($\rho = 0.89$, $P < .001$; Fig. 3). When comparing the predicted model responses ±1 component size with that of the Arthroplasty Size Predictor, the overall percent concordance was 94.6% for the tibia components and 95.2% for the femoral components.

## Discussion

To our knowledge, this study is the only study of its magnitude to be completed by a single, fellowship-trained surgeon using a single TKA system. Similar to other reports in the literature, we were able to create a statistical model using patient characteristics that accurately predict tibial and femoral components within ±1 size for use in preoperative planning for TKA surgery. Furthermore, our predicted results (within ± one component size) are in high agreement with the electronic application–predicted results

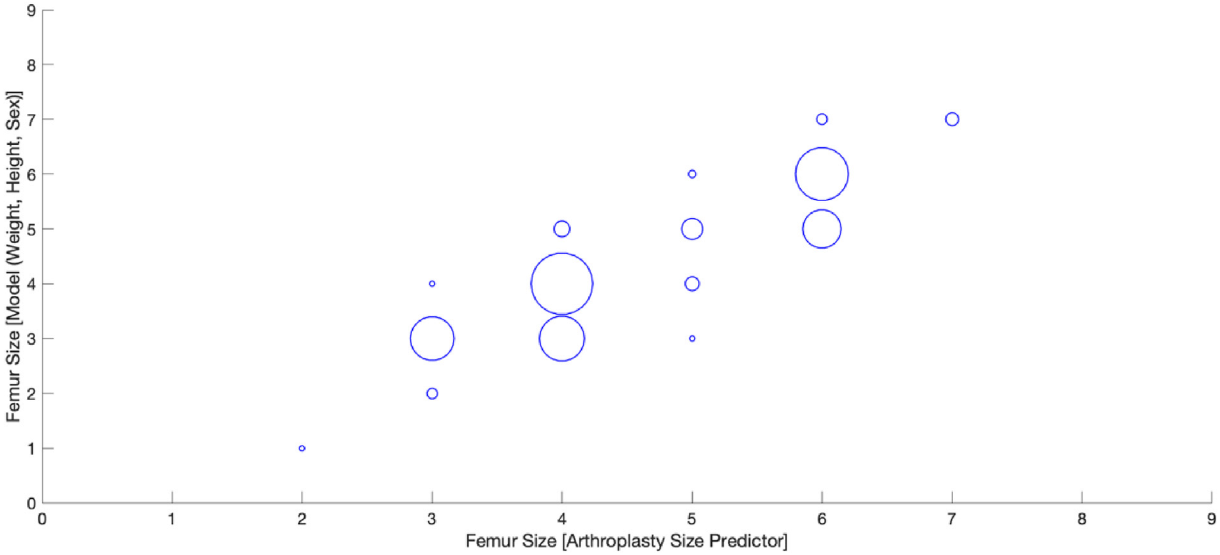

**Figure 3.** Relationship between ordinal regression model–predicted femoral component size and Arthroplasty Size Predictor femoral component size results. The size of the bubble corresponds to the number of cases (ie, larger diameter = more cases).

described by Sershon et al and may be used to improve operative efficiency by surgeons seeking a widely available electronic application [13].

Sershon et al. highlighted the discrepancies in literature regarding digital templating for TKA and were able to accurately template tibial and femoral implants within one size in 97% and 94%, respectively, using sex, height, and weight as predictors [9]. Sershon et al. developed an electronic application (Arthroplasty Size Predictor, Apple App Store, 2017) that allows surgeons to quickly calculate the tibial and femoral size for multiple vendors using sex, height, and weight [13]. The patients used to formulate the electronic application comprised mostly of competitor TKA systems and only included 21 patients with the system chosen by the principal surgeon in our study. Our study, conducted at a different institution, further validate the results of the study by Sershon et al. as the Arthroplasty Size Predictor application predicted 91% (n = 441/484) within ± component size for both tibias and femurs in our patient sample.

Our findings were similar to that of Blevins et al. who found that height had the strongest correlation with implant sizes of femoral and tibial components [14]. However, the author also found moderate association between weight and implant size, which was not seen in our study. Gao et al. also found a strong linear correlation between weight and implant sizes [15].

Ren et al. analyzed 199 knees using a different total knee system than used in our study and used ordinal regression to formulate an equation that predicted the final tibial size. They were able to predict the final tibial size within one size difference 94% of the time on testing data when sex, age, and weight were used as independent variables. Although age was not a significant predictive factor in our model, our results (%) of predicted tibial component size within ± component size are similar to their reported results. The results at our institution are similar to what have been found at a large academic center [10].

The cost of implants is widely scrutinized; however, additional expenses associated with surgery are rarely discussed. The trays carrying the implant trials are often large and stocked sparingly because of the cost of acquisition. Each tray includes a vast range of implants, including the extremes of sizes. The large size places a burden on the sterilization department, surgical staffer, and implant manufacturer. Improving preoperative planning will allow surgeons to decide the final component size more efficiently, thereby reducing total surgical time and costs associated with instrument maintenance/sterile processing [11].

The results of our study may also help reduce the costs associated with instruments and surgery. A study by Nast and Swords demonstrated the cost of instrument maintenance and sterilization to be approximately $0.51-$0.77 per instrument [16]. Nast and Swords also found that only 13-21.9% of instruments opened were used [16]. The cost of acquiring implant trials prohibits many facilities from stocking a sufficient amount of reserve to replace sets contaminated or unprocessed. Contamination within the operating room plays a large factor in the surgical flow. Delay due to contamination lengthens an operative day and often increases the cost to a facility to staff an operative room with employees who are often paid by the hour. The use of preoperative templating can reduce the cost of sterile processing when trials and cutting guides of planned sizes that are within one component size are opened, saving an estimated $9612 annually per surgeon [7].

Although preoperative templating may improve a surgeon's intraoperative efficiency, it is not a substitute for intraoperative trialing. It should be noted that even when the tolerance of prediction was increased to ±1 component size, our results were not 100% accurate. Time spent trialing femoral and tibial component size adds to the total surgical time. With a wide range of proficiency in surgeons performing TKA and a wide range of surgical time, the time to the final component size can significantly increase the risk of complications to the patient. Cheng et al. found that for each 15, 30, and 60 minutes, the risk of surgical site infection increases by 13%, 17%, and 37%, respectively [17].

There are limitations to this study. First, it only accounts for a single TKA system and may not be transferable to other implant designs with our ordinal regression equation. Nevertheless, it does leave room for further studies for individual implant designs. Second, the performing surgeon routinely educates patients on weight control and will delay surgery until the proper weight is obtained. A weight cutoff limits the range of patients included; however, we believe the weight restriction is universally accepted among other high-volume surgeons. Third, the literature has shown that different races may require larger or smaller component sizes, yet our study did not account for patient race as a predictor, which may have impacted our results [18,19]. Fourth, the data used in our study were easily accessible and did not include other demographic, anthropometric, or radiographic variables that may improve predictive capability [20]. Fifth, although our patient population is relatively large, our sample does not include all sizes available in this particular TKA system, thus possibly limiting the prediction potential. Finally, we would ideally have an equal proportion of cases for each component size to improve our accuracy. However, we identified 13.5% (n = 65/484) of tibias and 12% (n = 58/484) of femurs implanted with components in the extreme of sizes. We classified components with a femoral or tibial implant size $\leq 2$ and $\geq 7$ as the extreme of sizes. When evaluating these extremes, predicting ±1 component size decreased to 86.2% (n = 56/65) for the tibia and 77.6% (n = 45/58) for the femur (Table 2). The discrepancy of this subset analysis is likely due to the smaller number of cases available at both ends of the extremes. Future studies should aim to increase the total number of patients included in the analysis to overcome the sampling deficiency in patients implanted with a component classified in the extreme of size.

## Conclusion

Our findings demonstrate femoral and tibial component sizes of the TKA can be predicted with 54.0% accuracy for the tibia and 51.1% for the femur. Our predictive model's accuracy improved to 94.4% for the tibia and 93.4% for the femur within ±1 component size. In addition, our findings have a high concordance with a widely available electronic application and may be a useful tool for orthopaedic surgeons to preoperative template TKA [13]. Our predictive model can be used by surgeons and may improve the time required for intraoperative trialing, decrease operative waste, and improve operative efficiency but is not a substitute for intraoperative trialing. In addition, no additional time is consumed in collecting patient demographics as all patients preoperatively have their height and weight measured. Future studies can include prospectively collecting patient demographics and using limited trial sizes to assess this templating model's accuracy and cost-effectiveness.

## Conflict of interests

The authors declare there are no potential conflicts of interest.

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