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Original research

Preoperative radiographic valgus alignment predicts the extent of lateral soft tissue release and need for constraint in valgus total knee arthroplasty

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ABSTRACT

Background: In total knee arthroplasty (TKA) for valgus knees, the decision to use a constrained implant is often made intraoperatively depending on the extent of soft tissue releases performed and residual soft tissue imbalance. The purpose of this study is to determine if preoperative radiographic criteria of valgus knees can predict the extent of soft tissue releases required and the level of constraint needed to balance the knee during TKA.

Methods: A single surgeon's 807 consecutive TKA standing hip-knee-ankle radiographs from 2007-2012 were analyzed. One hundred eighty-seven valgus knees were identified and annotated. Statistical univariate and multivariate analyses were performed for both outcomes, lateral release and articulation, to assess the association with risk factors of gender, age, and preoperative radiographic markers of valgus deformity. A *P*-value <.05 represented a significant difference between groups.

Results: Use of a constrained articulation was associated with increased valgus deformity (mechanical hip-knee-ankle angle, $P < .0001$) and extent of lateral soft tissue release ($P < .0001$). No relationship existed between the use of a constrained articulation and age or gender ($P > .05$). A preoperative anatomic tibiofemoral valgus angle of >16.8° was associated with the use of a constrained articulation during surgery.

Conclusions: Our data demonstrate that preoperative radiographic characteristics of the valgus knee can be utilized to predict the extent of lateral soft tissue release and whether a constrained articulation will be required in TKA. This will provide surgeons with useful information to offer accurate preoperative counseling to patients and to ensure that the appropriate prosthetic parts are available during surgery.

Introduction

In total knee arthroplasty (TKA) in patients with preoperative valgus alignment, 2 objectives for a successful outcome are correction of the deformity and soft tissue balancing [1,2]. Soft tissue contractures are often part of the pathology present in arthritic knees. These contractures are addressed during the time of surgery in TKA to create symmetric and balanced flexion and extension gaps. In valgus knees, the lateral soft tissues including the iliotibial band (ITB), lateral collateral ligament (LCL), popliteus tendon, and posterolateral capsule contract; with increasing deformity, the corresponding medial soft tissues may also become attenuated [1,3]. Although numerous methods and sequences of soft tissue balancing have been described to manage the valgus knee during TKA [1,4-15], all have the final goal of producing a stable and balanced knee [2]. Despite these prior reports we are unaware of precise radiographic criteria that can be used preoperatively to help predict the extent of soft tissue contracture

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releases that will be required to balance the knee intraoperatively, or whether a constrained articulation will be needed to provide stability in the presence of residual soft tissue imbalance [16]. This information would be helpful to the surgeon for both operative planning, to ensure that appropriate prosthetic components are available, and for preoperative patient counseling [17].

Therefore, we asked the following questions: (1) Does the degree of valgus alignment seen on preoperative radiographs correlate with the extent of lateral soft tissue release and (2) can the degree of valgus deformity seen on preoperative radiographs be used to predict the level of TKA component constraint?

Material and methods

A single surgeon's (H.D.C.) consecutive TKA series from January 2007 to December 2012 was retrospectively analyzed. Eight hundred seven long-standing hip-knee-ankle radiographs were screened by O.G. and T.P.M. A valgus knee was defined as one in which the center of the knee was medial to the mechanical axis of the limb on long-standing hip-to-ankle radiographs. One hundred eighty-seven valgus knees were identified and those radiographs were reviewed in detail (by O.G.). Postoperative full-length hip-to-ankle radiographs were taken 6 weeks postoperatively and were analyzed as well. For each knee, the following radiographic parameters were determined: (1) the mechanical hip-knee-ankle angle as determined by the intersection of the line drawn from the center of the femoral head to the center of the knee with the line from the center of the knee to the center of the talus; (2) the mechanical axis of the limb, defined as a line from the center of the femoral head to the center of the talus; (3) the distance from the center of the knee to the mechanical axis of the limb; (4) the anatomic tibiofemoral angle, defined as the angle between a line drawn from the center of the knee proximally up the center of the femoral canal, and a line from the center of the tibial plateau distally down the center of the tibial canal (Fig. 1); (5) the mechanical femoral condylar angle, defined as a line tangent to the distal aspect of the medial and lateral femoral condyles and the femoral mechanical line; (6) the anatomic femoral condylar angle, defined as a line tangent to the distal aspect of the medial and lateral femoral condyles and a line through the middle of the femoral canal; (7) the mechanical tibial condylar angle, defined as a line tangent to the medial and lateral articular surfaces of the tibial plateau and the mechanical tibial line; and (8) the anatomic tibial condylar angle, defined as a line tangent to the medial and lateral articular surfaces of the tibial plateau and the anatomic tibial line.

Operative reports for each knee were reviewed to retrieve the gender and age of each patient at the time of surgery, the extent of soft tissue releases performed, and final component utilized (posterior stabilized vs constrained). The extent of soft tissue lateral release was scored from 1 to 4. A score of 1 indicated no lateral release performed. A score of 2 was for pie crusting of the iliotibial band only. A score of 3 was for pie crusting of the ITB with a transverse release of the posterolateral capsule. A score of 4 was for pie crusting of the ITB plus release of the popliteus and/or LCL from the lateral femoral condyle.

Surgical technique

The senior author employed the following sequential releases consistently throughout the study period. These releases have been previously described and associated with excellent clinical

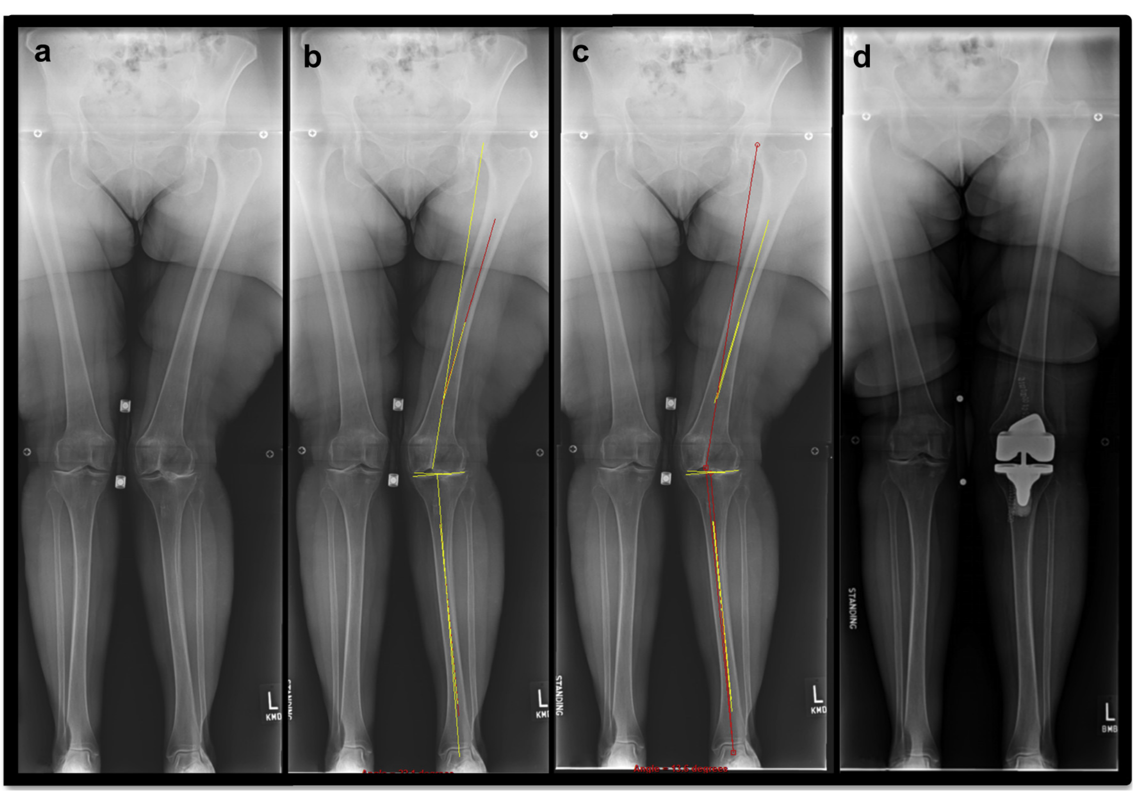

Figure 1. (a) Preoperative long-standing radiographs demonstrating valgus deformity of the left lower extremity. (b) Anatomic tibiofemoral angle of 22.1° (red lines). (c) Mechanical hip-knee-ankle angle of 13.6° (red lines). (d) Postoperative long-standing radiographs demonstrating correction of the deformity (this patient required a type 3 release of the lateral soft tissue contractures) and use of a constrained articulation.

outcomes [6]: first, at the level of the tibial bone cut, a #15 surgical blade was used to make a transverse incision through the posterolateral capsule, beginning anterior to the popliteus tendon. Next, multiple horizontal stab incisions were made through the ITB, LCL, and lateral capsule at the level of the joint line, as well as proximal to the joint line until medial-lateral soft tissue balance was achieved. After the lateral side of the knee was lengthened, a second laminar spreader was inserted into the lateral joint space and used to gently stretch and tension the soft tissue structures. Following the lateral side lengthening, an appropriately sized spacer block that filled the extension space was used to evaluate the medial and lateral balance. Typically, this spacer block was 2-4 mm thicker than the initial block that was used prior to soft tissue releases but was dependent on the initial asymmetry and magnitude of the valgus deformity, and whether the deformity was correctable on initial evaluation under anesthesia. The knee was then flexed and the symmetry of the flexion and extension gaps was assessed. If soft tissue tension was not symmetric (difference greater than 1-2 mm), additional pie crusting was performed in the same way as described above.

The decision to convert to a constrained articulation was made after all soft tissue releases were performed and there was residual gapping of the lateral joint space of more than 1-2 mm when the lower extremity was placed in a figure-4 position and a varus stress applied. In addition, a constrained articulation was also used when significant medial attenuation was present and residual medial laxity remained despite extensive lateral soft tissue release.

Statistical analysis

In this analysis, we provided the overall descriptives; frequencies and proportions for categorical variables, and mean and standard deviation for continuous variables. Univariate analysis was performed to assess the association of both outcomes, articulation and lateral release, with risk factors, such as gender, age, and radiographic markers of valgus deformity. Nonparametric tests, the Wilcoxon rank sum test and the Kruskall Wallis test, were utilized to compare for population mean shift between 2 groups and among 3 or more groups, respectively. The Pearson chi-square test was used to test for univariate associations between categorical values. The Pearson correlation coefficient (r) was also calculated to assess pairwise linear associations between the continuous variables and lateral release. All risk factors with P value $\leq$.20 obtained from the univariate analysis were considered for inclusion in the multivariate analysis. The multivariate analysis for the outcome articulation used a logistic model which did not show any lack of fit and was highly predictive.

Multivariate regression was used to model the outcome of lateral release and the adjusted R^2 was performed to provide a set of best models. In order to provide the final model, the best models and the collinearity in each model were evaluated. The significance level was set at 0.05. A cutoff analysis was performed to identify a preoperative degree of valgus deformity, above which a constrained articulation and increased lateral release was utilized. This was based on a univariate logistic model, which used the receiver operating characteristic curve and the Youden cutoff index [18]. Statistical analyses were performed using the statistical software packages SAS Studio 3.4 (SAS Institute, Cary, NC).

Results

Among the 807 consecutive patients who underwent TKA during the designated study period, 187 (23%) patients were identified as having valgus alignment (center of knee medial to mechanical axis of the limb). Of patients with preoperative valgus alignment, 39 (20.9%) patients were male and 148 (79.1%) patients were female (Table 1). Mean age at the time of surgery was 70.3 years (41.0-88.0). Posterior stabilized implants were used in 157 (84.0%) of knees and constrained implants with added stability in the coronal plane were used in 30 (16.0%) knees. Prostheses from 3 manufacturers were used: implants from manufacturer 1 (Stryker, Mahwah, NJ) were used in 104 (55.6%) patients, manufacturer 2 (Zimmer, Warsaw, IN) in 80 (42.8%), and manufacturer 3 (Biomet, Warsaw, IN) in 3 (1.6%). Soft tissue lateral release was not required (score of 1) in 62 knees (33.3%); pie crusting of iliotibial band only (score of 2) was used in 6 knees (3.2%); pie crusting of the ITB and a transverse release of the posterolateral capsule at the level tibial bone cut was performed (score of 3) in 100 (53.8%) patients; and pie crusting of the ITB, transverse release of the posterolateral capsule, plus release of the popliteus and/or LCL from the lateral femoral condyle (score of 4) in 18 (9.7%) of patients. The mean score of lateral release in all patients with valgus alignment was 2.4. The frequencies; mean, median, first, and third quartile; minimum, maximum, and range of all annotated measurements are provided for both preoperative and postoperative radiographs (Table 1).

Table 1
Demographics and outcomes.

	Total (n = 187)
Gender	
Male	39 (20.9%)
Female	148 (79.1%)
Articulation	
Posterior stabilized	157 (84.0%)
Constrained	30 (16.0%)
Component used	
Stryker	104 (55.6%)
Zimmer	80 (42.8%)
Biomet	3 (1.6%)
Lateral release	
No soft tissue release required	62 (33.3%)
Pie crusting of IT band only	6 (3.2%)
Pie crusting of ITB with transverse release of posterolateral capsule	100 (53.8%)
Pie crusting of ITB plus release of popliteus and/or LCL from lateral femoral condyle	18 (9.7%)
Age at surgery	
Mean (SD)	70.3 (9.0)
Millimeter to midline from the mechanical axis	
Mean (SD)	25.9 (16.2)
Anatomic tibiofemoral angle	
Mean (SD)	14.1 (4.2)
Mechanical hip-knee-ankle angle	
Mean (SD)	7.0 (4.1)
Preoperative mechanical femoral condylar angle	
Mean (SD)	5.0 (2.0)
Preoperative anatomic femoral condylar angle	
Mean (SD)	11.2 (2.6)
Preoperative mechanical tibial condylar angle	
Mean (SD)	2.1 (1.8)
Preoperative anatomic tibial condylar angle	
Mean (SD)	2.5 (2.3)
Postoperative mechanical hip-knee-ankle angle	
Mean (SD)	−0.3 (2.9)

SD, standard deviation.

Increased preoperative valgus deformity (mechanical hip-knee-ankle angle, anatomic tibiofemoral angle, and millimeter to mechanical axis; $P < .0001$) and extent of lateral soft tissue release ($P < .0001$) were associated with the use of a constrained articulation. No relationship was found between the type of articulation (posterior stabilized or constrained) and gender or age of the patient ($P = .72$ and $P = .50$, respectively; Table 2). Additionally, there was no association between the type of articulation and implant manufacturer ($P = .55$). In addition, the use of a constrained

Table 2
Characteristics by articulation.

	Posterior stabilized ($n = 157$)	Constrained ($n = 30$)	Total ($n = 187$)	P value
Gender				.7154[a]
Male	32 (20.4%)	7 (23.3%)	39 (20.9%)	
Female	125 (79.6%)	23 (76.7%)	148 (79.1%)	
Component used				.5458[a]
Stryker	89 (56.7%)	15 (50.0%)	104 (55.6%)	
Zimmer	65 (41.4%)	15 (50.0%)	80 (42.8%)	
Biomet	3 (1.9%)	0 (0.0%)	3 (1.6%)	
Lateral release				<.0001[b]
Mean (SD)	2.2 (1.0)	3.4 (0.7)	2.4 (1.1)	
Age at surgery				.5048[b]
Mean (SD)	70.0 (9.3)	71.8 (6.7)	70.3 (9.0)	
Millimeter to mechanical axis from midline				<.0001[b]
Mean (SD)	22.8 (13.2)	42.2 (20.6)	25.9 (16.2)	
Anatomic tibiofemoral angle				<.0001[b]
Mean (SD)	13.1 (3.4)	18.7 (5.0)	14.1 (4.2)	
Mechanical hip-knee-ankle angle				<.0001[b]
Mean (SD)	6.2 (3.4)	11.0 (4.9)	7.0 (4.1)	
Preoperative mechanical femoral condylar angle				.0122[b]
Mean (SD)	4.8 (1.9)	6.0 (2.6)	5.0 (2.0)	
Preoperative anatomic femoral condylar angle				.0491[b]
Mean (SD)	11.1 (2.2)	11.8 (4.4)	11.2 (2.6)	
Preoperative mechanical tibial condylar angle				<.0001[b]
Mean (SD)	1.8 (1.4)	3.8 (2.5)	2.1 (1.8)	
Preoperative anatomic tibial condylar angle				<.0001[b]
Mean (SD)	2.0 (1.7)	5.0 (3.3)	2.5 (2.3)	
Postoperative mechanical hip-knee-ankle angle				.0913[b]
Mean (SD)	−0.1 (2.8)	−0.9 (3.2)	−0.3 (2.9)	

SD, standard deviation.
[a] Chi-square test.
[b] Wilcoxon test.

articulation was associated with tibial and femoral anatomy about the knee that contributes to overall valgus alignment (mechanical femoral condylar angle, anatomic femoral condylar angle, mechanical tibial condylar angle, and anatomic tibial condylar angle; $P < .05$). Postoperatively, there was no difference in alignment as measured on the mechanical hip-knee-ankle angle between subjects in the posterior stabilized vs constrained group ($P > .05$).

The extent of lateral release was not associated with gender or component brand ($P > .05$; Tables 3 and 4). Significant correlations between lateral release and radiographic measurements of valgus deformity were demonstrated with pairwise Pearson correlation coefficients and corresponding P value for linear associations (Table 5).

Multivariate regression model for lateral release demonstrated a positive and significant association between the severity of valgus deformity (measured in millimeter from the mechanical axis of the lower extremity to the midline of the knee in the coronal plane) and the extent of lateral release (slope 0.037, $P < .0001$) (Table 6). For lateral release, there was no association with age at surgery (slope 0.002, $P = .7537$) or preoperative anatomic femoral condylar angle (slope −0.008, $P = .7684$). There was a negative and significant association between postoperative mechanical femoral condylar angle and extent of lateral release (slope −0.13, $P < .0001$).

Finally, the univariate logistic model, which used the receiver operating characteristic curve and the Youden cutoff index, demonstrated a cutoff value of 16.8° (anatomic tibiofemoral angle) and 8.5° (mechanical hip-knee-ankle angle), above which there was increased odds of using a constrained articulation (Table 7). The same analysis demonstrated that above 12.3° (anatomic tibiofemoral angle) and 5.3° (mechanical hip-knee-ankle angle), there is increased odds of performing more extensive (type 3 or 4) lateral soft tissue releases ($P < .0001$) (Table 7).

Discussion

In TKA for valgus knees, correction of the deformity and accurate soft tissue balancing are critical for the functional outcome and survival of the prosthesis [1,2,7]. Depending on the extent of the soft tissue releases required and any residual soft tissue imbalance that may persist, the surgeon may elect to use a constrained articulation to provide additional stability in the coronal plane. Despite favorable mid-term results that have been previously reported using constrained articulations in primary TKA in low demand patients, concerns persist that use of increased constraint may be associated with an increased risk of polyethylene wear or aseptic loosening. Consequently, selective use of constrained articulations is recommended [17,19-21]. Therefore, it would be helpful if preoperative criteria were available to help the surgeon identify those knees where more soft tissue releases and additional

Table 3
Lateral release by gender.

	Male ($n = 39$)	Female ($n = 148$)	Total ($n = 187$)	P value
Lateral release				.2808[a]
n	39	147	186	
Mean (SD)	2.2 (1.2)	2.4 (1.0)	2.4 (1.1)	

SD, standard deviation.
[a] Wilcoxon test.

Table 4
Lateral release by manufacturer.

	Stryker ($n = 104$)	Zimmer ($n = 80$)	Biomet ($n = 3$)	Total ($n = 187$)	P value
Lateral release					.3787[a]
n	103	80	3	186	
Mean (SD)	2.3 (1.0)	2.5 (1.1)	2.3 (1.2)	2.4 (1.1)	

SD, standard deviation.
[a] Kruskal-Wallis test.

Table 5
Pearson (linear) correlation coefficients for linear associations with lateral release.

Risk factor	*r*	*P* value
Age at surgery	0.0043	.9537
Millimeter to midline from mechanical axis	0.5457	.0000
Anatomic tibiofemoral angle	0.5382	.0000
Mechanical hip-knee-ankle angle	0.5638	.0000
Preoperative mechanical femoral condylar angle	0.2673	.0003
Preoperative anatomic femoral condylar angle	0.0993	.1824
Preoperative mechanical tibial condylar angle	0.2961	.0000
Preoperative anatomic tibial condylar angle	0.3890	.0000
Preoperative medial joint space on standing films	0.3391	.0000
Preoperative medial joint space adjusted for magnification	0.3893	.0005
Postoperative mechanical hip-knee-ankle angle	−0.2726	.0003
Postoperative mechanical femoral condylar angle	−0.3158	.0000
Postoperative mechanical tibial condylar angle	−0.1209	.1153

Note: This table provides the pairwise Pearson correlation coefficient (r) and corresponding P value for testing whether the correlation coefficient is different from 0 vs not. For example, from row 3, we conclude that the lateral release and anatomic tibiofemoral angle are positively correlated or associated with $r = 0.54$ ($P < .0001$).

constraint may be needed. In particular, this would facilitate surgical planning and efficiency by making sure that appropriate prosthesis options are available when needed and aiding in case sequence. Furthermore, defined criteria may facilitate preoperative patient counseling by more accurately setting expectations and communicating prosthesis selection. Therefore, the goals for our study were to determine the following: (1) if the degree of valgus alignment seen on preoperative radiographs correlates with the extent of lateral soft tissue release and (2) if it can predict the ultimate component selection in terms of level of constraint.

Our data show that preoperative radiographic characteristics of the valgus knee can be utilized to predict the extent of lateral soft tissue release and whether a constrained articulation will be required in TKA. We sought to define a “cutoff” value from our data that could be utilized prospectively to predict implant selection and soft tissue release and identified an optimal value of 16.8°. The cutoff value is a measure of accuracy, which maximizes the difference between the true positives and false positives. Hence, we can conclude that an anatomic tibiofemoral angle above 16.8° measured on preoperative radiographs (or a mechanical hip-knee-ankle angle above 8.5°) would predict a greater need for use of a constrained articulation. Similarly, our results demonstrate that an anatomic tibiofemoral angle above 12.3° (or a mechanical hip-knee-ankle angle above 5.3°) significantly increases the likelihood that more extensive (type 3 or 4) lateral soft tissue release including pie crusting of the ITB, transverse release of the posterolateral capsule, and releases of the popliteus and/or LCL from the lateral femoral condyle will be needed (C-statistic = 0.83). Although these cutoff values provide useful information, it is important to note that each patient should ultimately be evaluated intraoperatively to determine the extent of soft tissue releases that need to be performed and soft tissue balance before the final determination of implant constraint is chosen. The use of spacer blocks following soft tissue releases to assess the soft tissue stability that has been achieved, in conjunction with consideration of the soft tissue structures that were released will ultimately determine the intraoperative decisions.

Table 6
Multivariate regression model for lateral release.

Risk factor	Slope	95% Confidence interval	*P* value
Age at surgery (Y)	0.002	(−0.012 to 0.017)	.7353
Millimeter to mechanical axis from middle of knee	0.036	(0.028-0.045)	<.0001
Preoperative anatomic tibial condylar angle	−0.007	(−0.059 to 0.044)	.7754
Postoperative mechanical femoral condylar angle	−0.132	(−0.194 to −0.069)	<.0001

Note: The lateral release is modeled using multivariate regression. We provide the beta estimates (slopes), their corresponding 95% confidence interval, and the P value. For example, in row 2, lateral release increases by about 4% (0.036, $P < .0001$) on average for every unit increase of “millimeter to mechanical axis from middle of knee.”

Although some surgeons try to avoid the use of a constrained articulation whenever the soft tissues provide enough stability, others have proposed that a primary constrained articulation used in the select patient can still have good results [1,8,16,22-26]. In this study, the senior operating surgeon (H.D.C.) assessed residual laxity intraoperatively (gapping of the lateral joint space of more than 2 mm when the lower extremity was placed in a figure-4 position and a varus stress applied) after all soft tissue releases were performed and used this or the presence of significant medial attenuation as criteria to convert to a constrained prosthesis. The consistency of this methodology is supported by the data, which demonstrate no difference in rates of constrained articulation when using prostheses from manufacturers 1 and 2 (there were too few cases with manufacturer 3 to allow analysis). This is important because when using the prostheses from manufacturer 2, it is much more difficult to switch to a constrained prosthesis due to the need for repeat bone cuts and use of a revision type femoral component vs using a constrained polyethylene insert with a primary femoral component that is possible with manufacturer 1. Similarly, some surgeons consider the factors of older age, gender, and/or preoperative activity level in the decision to use a constrained articulation but this was not demonstrated in our series, again suggesting that the decision to use constraint was primarily determined by an evaluation of the adequacy of soft tissue stability and the releases that had been performed.

Limitations of the study include those inherent to retrospective, single surgeon studies, including incomplete records and the bias introduced by a single operative experience. However, all our subjects had full-length standing films that allowed accurate assessment of the valgus deformity and bony anatomy with multiple measurements. One important limitation is that our findings and conclusions are based on the senior author's experience and operative decision making and may not apply to other surgeons. In particular, other surgeons with different operative abilities and education may have different criteria for what constitutes acceptable soft tissue balance, or be able to achieve acceptable stability with less releases or constraint. Although this may be considered a weakness of the study, the singular experience does have potential benefits as well. The consistent philosophy and surgical implementation perhaps improved consistency with regards to both the extent of lateral soft tissue releases that were used, and the decision to convert to a constrained articulation. It is also important to note that the clinical outcomes in this cohort of patients were not collected, which is an important limitation. However, excellent clinical results using this surgical technique and intraoperative decision criteria have been previously reported by both the senior author and other groups [6,7,14].

An additional limitation of the study is that the radiographic measurements were made once by the lead author only and therefore no intra- or inter-rater reliability could be determined. Finally, although our study utilized long-standing hip-to-ankle radiographs that may not be readily available in other centers, we also evaluated radiographic criteria including the anatomic tibiofemoral angle that can be determined from a short anteroposterior standing view of the knee that increases the utility of the findings to most centers performing TKA [27,28].

Table 7
Univariate logistic models and cutoff values.

Variable	Risk factor	Odds	95% Confidence interval	*P* value	*C*	Cutoff
Articulation (constrained vs PS)	Anatomic tibiofemoral angle	1.425	(1.25-1.625)	.0001	0.83	16.8
Articulation (constrained vs PS)	Mechanical hip-knee-ankle angle	1.362	(1.206-1.537)	.0001	0.79	8.5
Lateral release (type 3, 4) vs (1, 2)	Anatomic tibiofemoral angle	1.50	(1.317-1.708)	.0001	0.83	12.3
Lateral release (type 3, 4) vs (1, 2)	Mechanical hip-knee-ankle angle	1.60	(1.383-1.850)	.0001	0.85	5.3

PS, posterior stabilized.

Conclusions

Preoperative radiographic criteria of the valgus knee prior to primary TKA can be utilized to predict the extent of lateral soft tissue release that will be needed intraoperatively, and whether a constrained articulation will be required to provide additional stability. This is useful information for surgeons and may facilitate more accurate preoperative counseling to patients with valgus deformities regarding the type of prosthesis that will be used. Furthermore, it may improve operating room efficiency by allowing better case sequence planning and ensuring that appropriate prosthetic parts and instrument trays are available when likely to be needed.

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