Alignment Analyses in the Varus Osteoarthritic Knee Using Computer Navigation

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Abstract

Osteoarthritic (OA) knees with severe extension varus deformity seem to have correspondingly more severe flexion varus, especially beyond a certain tibiofemoral angle. Clinical measurement of flexion varus and fixed flexion deformity (FFD), which had been difficult to perform because of the spatial alignment of the knee in flexion, was recently made possible with computer navigation.

We conducted a study to evaluate the relationship of extension and flexion varus in OA knees and to determine whether severity of FFD in the sagittal plane correlates with severity of coronal plane varus deformity. The study included 317 consecutive cases of computer-navigated total knee arthroplasty performed on OA knees with varus deformities. Three sets of values were extracted from the navigation data: varus angle at maximal knee extension, 90° knee flexion, and maximal knee extension. Correlation analyses were performed for extension and flexion varus, FFD, and coronal plane deformity.

OA knees with extension varus of more than 10° had an incremental likelihood of more severe flexion varus. When the extension varus angle exceeded 20°, probability became almost certainty. There was no correlation between FFD and coronal plane varus deformity.

Osteoarthritic (OA) knees with varus deformities commonly present with tight, contracted medial collateral ligaments and soft-tissue sleeves.[1] More severe varus deformities require more extensive medial releases on the concave side to optimize flexion-extension gaps. Excessive soft-tissue releases in milder varus deformities can result in medial instability in flexion and extension.[2-4] Misjudgments in soft-tissue release can therefore lead to knee instability, an important cause of early total knee arthroplasty (TKA) failures.[2,5,6] Some authors have reported difficulty in coronal plane balancing in knees with preoperative varus deformity of more than 20°.[4,7]

Surgeons often refer to varus as a description of coronal malalignment, mainly with the knee in extension. In the surgical setting, however, descriptions are given regarding differential medial soft-tissue tightness in extension and flexion. Balancing the knee in extension may not necessarily balance the knee in flexion. Thus, there is the concept of extension and flexion varus, which has not been well described in the literature. Releases on the anterior medial and posterior medial aspects of the proximal tibia have differential effects on flexion and extension gaps, respectively.[2]

Intraoperative alignment certainly has a pivotal role in component longevity.[8] Since its advent in the 1990s, use of computer navigation in TKA has offered new hope for improving component alignment. Some authors routinely use computer navigation for intraoperative soft-tissue releases.[9] A recent meta-analysis found that computer-navigated surgery is associated with fewer outliers in final component alignment compared with conventional TKA.[10]

Increased use of computer navigation in TKA at our institution in recent years has come with the observation that knees with severe extension varus seem to have correspondingly more severe flexion varus. Before computer navigation, coronal alignment of knees in flexion was almost impossible to measure because of the spatial alignment of the knees in that position.

We conducted a study to evaluate the relationship of extension and flexion varus in OA knees and to determine whether severity of fixed flexion deformity (FFD) in the sagittal plane correlates with severity of coronal plane varus deformity. We hypothesized that there would be differential varus in flexion and extension and that increasing knee extension varus would correlate closely with knee flexion varus beyond a certain tibiofemoral angle. We also hypothesized that severity of sagittal plane deformity will correlate with the severity of coronal plane deformity.

Patients and Methods

Data Collection

After this study was approved by our institution's ethics review committee, we prospectively collected data from 403 consecutive computer-navigated TKAs performed at our institution

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between November 2008 and August 2011. Dr. Tan, who was not the primary physician, retrospectively analyzed the radiographic and navigation data.

Each patient's knee varus-valgus angles were captured by Dr. Teo, an adult reconstruction surgeon, in standard fashion from maximal extension to 0°, 30°, 45°, 60°, 90°, and maximal flexion. An example of standard data capture appears in **Table 1**. With varus-hyperextension defined as –0.5° or less (more negative), neutral as 0°, and valgus-flexion as 0.5° or more, there were 362 varus knees, 41 valgus knees, and no neutral knees.

Study inclusion criteria were OA and varus deformity. Exclusion criteria were rheumatoid arthritis, other types of inflammatory arthritis, neuromuscular disorders, knees with valgus angulation, and incomplete data (**Table 2**). **Figure 1** summarizes the inclusion/exclusion process, which left 317 knees available for study. Cases of incomplete data were likely due to computer errors or to inadvertent movement when navigation data were being acquired during surgery.

In conventional TKA, the main objective is to equalize flexion-extension gaps with knee at 90° flexion and 0° extension. The ability to achieve this often implies the knee will be balanced throughout its range of motion (ROM). From the data for the 317 study knees, 3 sets of values were extracted: varus angles from maximal knee extension (extension varus), varus angles from 90° knee flexion (flexion varus), and maximal knee extension. All knees were able to achieve 90° flexion.

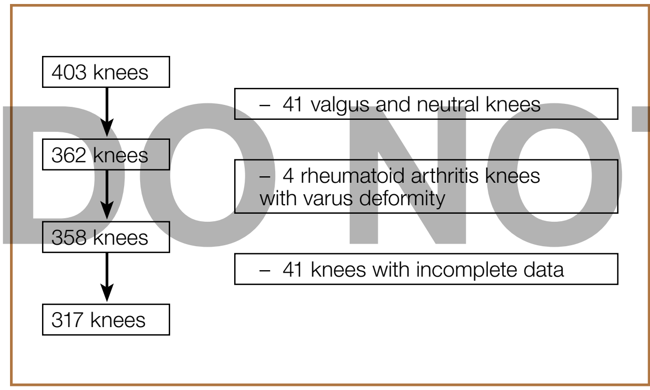

Figure 1. Flowchart of inclusion and exclusion process.

Table 1. **Example of Standard Data Capture**

+	–	Min						Max
Flexion	Hyperextension	–1.0°	+0.0°	+30.0°	+45.0°	+60.0°	+90.0°	+130.5°
Valgus	Varus	–6.5°	–6.5°	–7.0°	–6.5°	–6.0°	–3.5°	–0.5°

Table 2. **Example of Data Capture With Blanks in Patient's Table**

+	–	Min						Max
Flexion	Hyperextension	+15.5°	+0.0°	+30.0°	+45.0 °	+60.0°	+90.0°	+128.0°
Valgus	Varus	–17.5°		–19.5°				–11.0°

Power Calculation

Our analysis used a correlation coefficient (r) of at least 0.5 at a 5% level of significance and power of 80%. With 317 knees, the study was more than adequately powered for significance.

Surgical and Navigation Technique

All patients underwent either general or regional anesthesia for their surgeries, which were performed by Dr. Teo. Standard medial parapatellar arthrotomy was performed. Navigation pins were then inserted into the femur and tibia outside the knee wound. Anatomical reference points were digitized per routine navigation requirements. (The reference for varus-valgus alignment of the femur is the mechanical femur axis defined by the digitized hip center and knee center, and the reference for varus-valgus alignment of the tibia is the mechanical tibia axis defined by the digitized tibia center and calculated ankle center. The ankle center is calculated by dividing the digitized transmalleolar axis according to a ratio of 56% lateral to 44% medial with the inherent navigation software.) Our institution uses an imageless navigation system (Navigation System II; Stryker Orthopedics, Mahwah, New Jersey).

The leg was then brought from maximal knee extension to maximal knee flexion to assess preoperative ROM, which indicates inherent flexion contracture or hyperextension. Varus-valgus measurements of the knee were then generated as part of the navigation software protocol. These measurements were obtained without additional varus or valgus stress applied to the knee and before any bony resection. The rest of the operation was completed using navigation to guide bony resection and soft-tissue balancing. The final components used were all cemented cruciate-substituting TKA implants. After component insertion, the knee was again brought through ROM from maximal knee extension to maximal knee flexion to assess postoperative ROM before wound closure.

Extension and Flexion Varus

As none of the patients in the flexion varus dataset (range, –0.5° to –19°) had a varus deformity of more than 20° at 90° flexion, we used a cutoff of 10° to divide these patients into 2 subgroups: less than 10° (237 knees) and 10° or more (80 knees). The extension varus dataset ranged from –0.5° to –24°. Incremental values of –0.5° to –24° in this dataset were then analyzed against the 90° flexion varus subgroups using logistic regression. A scatterplot of the relationship between extension and flexion varus is shown in **Figure 2**. The probability function was then derived and a probability graph plotted.

FFD and Extension and Flexion Varus

Maximal knee extension, obtained from intraoperative navigation measurements, ranged from –9° (hyperextension) to 33° (FFD) and maximal knee flexion ranged from 90° to 146°. Ninety-two knees had slight hyperextension, and 6 were neutral.

Of the 317 OA knees with varus deformity, 219 (69%) had FFD. This sagittal plane alignment parameter was analyzed against coronal plane alignment in maximal knee extension and 90° knee flexion to determine if increasing severity of FFD corresponds with increasing extension or flexion varus.

Statistical Analysis

Statistical analysis was performed with Stata 10.1 (Statacorp, College Station, Texas). Significance was set at $P < .05$.

Results

Extension and Flexion Varus

Patient demographic data are listed in **Table 3**. Univariate logistic regression analysis revealed that age ($P = .110$), body mass index ($P = .696$), and sex ($P = .584$) did not affect the association between preoperative extension and flexion varus.

Mean (SD) preoperative extension varus was –9.9° (4.80°), and mean (SD) preoperative flexion 90° varus was –7.02° (3.74°). Linear regression of the data showed a significant positive correlation between preoperative extension varus and flexion varus (Pearson correlation coefficient, 0.57; $P < .0001$). The probability function was determined as follows: Probability of having flexion varus of more than 10° = $1 / (1 + e^{-z})$, where $z = -4.014 - 0.265 \times$ extension varus. Plotting the probability graph of flexion varus against varus angles at maximal knee extension from the probability formula yielded a sigmoid graph (**Figure 3**). The most linear part of the graph corresponds to the 10° to 20° of extension varus (solid line), demonstrating an almost linear increase in the probability of having more than 10° flexion varus with increasing extension varus from 10° to 20°. For extension varus of 20° or more, the probability of having flexion varus of more than 10° approaches 1.

FFD and Extension and Flexion Varus

Mean (SD) preoperative maximal knee extension (analogous to FFD) was 4.41° (7.50°), mean (SD) extension varus was –9.9° (4.80°), and mean (SD) 90° flexion varus was –7.02° (3.74°). We did not find any correlation between preoperative FFD and preoperative flexion varus ($r = -0.02$; $P = .6583$) or extension varus ($r = -0.11$; $P = .046$) (**Figure 4**).

Postoperative Alignment

Of the 317 OA knees, 18 had incomplete navigation-acquired postoperative alignment data. The postoperative alignment of the other 299 knees at various degrees of knee flexion is illustrated with a box-and-whisker plot (**Figure 5**).

Knees With Severe Extension Varus

Fourteen of the 15 knees with severe extension varus (>20°) had flexion varus of more than 9° (range, –9° to –17.5°, with only 1 outlier, at –5°). For the 15 patients, maximal knee extension ranged from –9° hyperextension to 27.5° FFD. Six knees had slight hyperextension, and 9 had FFD demonstrating large variability in sagittal alignment. Despite severe preoperative coronal deformity, all 15 knees had satisfactory deformity correction. Preoperative and postoperative knee alignment data for these 15 knees appear in **Table 4** and **Figure 6**, respectively.

Discussion

OA varus knees represent a majority of the cases being managed by orthopedic surgeons. Soft-tissue contractures involving the

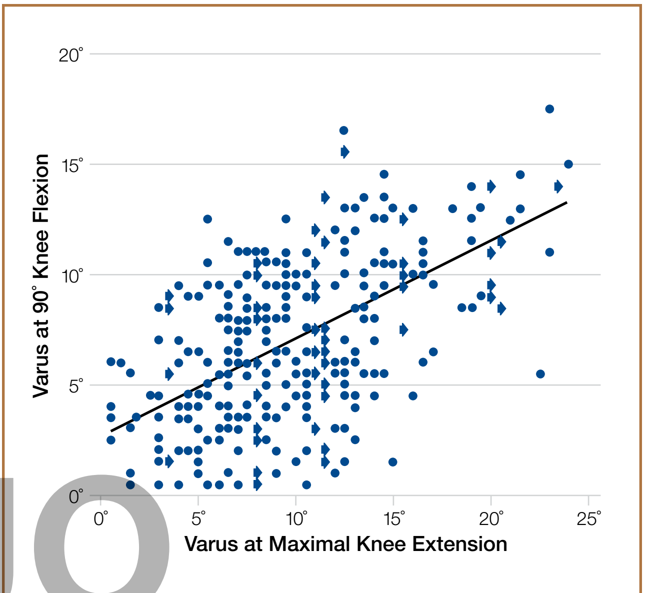

Figure 2. Scatterplot of extension varus versus flexion varus.

Table 3. **Patient Demographics**

317 Knees	Mean (Range)	Logistic Regression, *P*
Age, y	67.0 (40-86)	.110
Body mass index, kg/m^2	27.0 (16.0-43.3)	.696
Sex ratio, M:F	56:261	.584

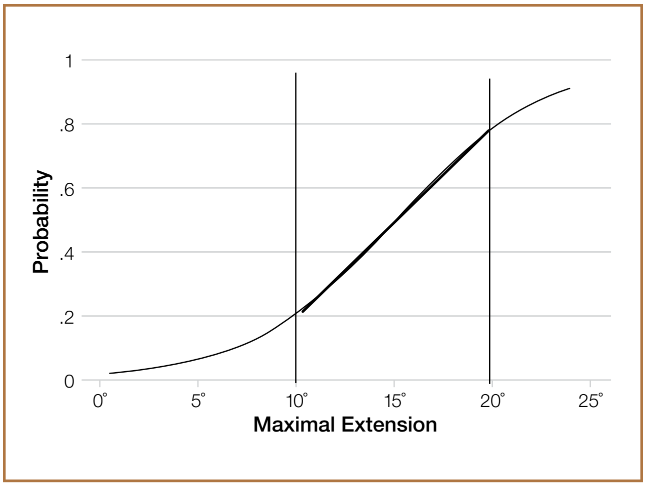

Figure 3. Probability graph of having flexion varus more than 10°.

medial collateral ligament (MCL), posteromedial capsule, pes anserinus, and semimembranosus muscle are commonly encountered. Bone loss may also occur on the tibial and femoral joint surfaces in knees with severe angular deformity. In an OA varus knee, bone loss tends to be mainly on the medial tibial plateau and usually on the posterior aspect of the tibia because flexion contractures often are concomitant with these marked deformities.[11] Therefore, a varus deformity is apparent whether the knee is extended or flexed. Our results showed a correlation between extension and flexion varus in OA varus knees. In contrast, for a valgus deformity, as bone loss can occur on both the tibial and femoral surfaces,[11] a similar correlation may not be seen. For that reason, and because there were only 41 valgus knees in this study, they were excluded. For FFD, soft-tissue contractures often involve both the posterior capsule and the posterior cruciate ligament (PCL). Posterior osteophytes often cause tenting of the posterior capsule in knees with FFD. Anteriorly, growth of osteophytes at the tibial spine and intercondylar notch of the femur can result in bony causes of restricted knee extension.[12]

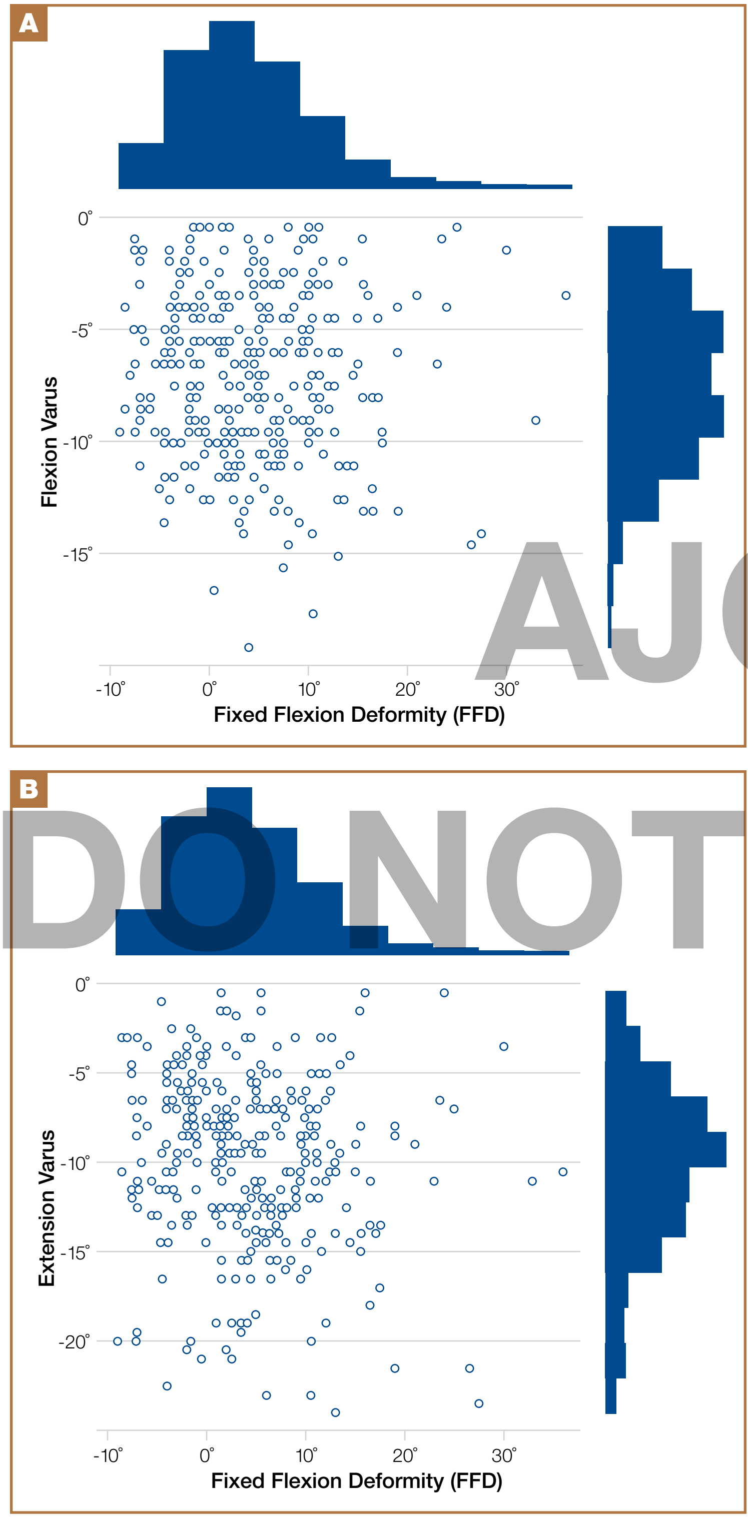

Figure 4. (A) Fixed flexion deformity (FFD) versus flexion varus. (B) FFD versus extension varus.

One would expect increased coronal plane angular deformity to correspond to more severe FFD in the sagittal plane because the same pathology affects soft tissue or bones in an OA knee in both planes. Interestingly, our study results proved otherwise. FFD did not correlate with degree of extension or flexion varus severity. This phenomenon has not been described in the literature likely because clinical measurements of flexion varus and FFD were difficult to perform because of the spatial alignment of the knee in flexion. In recent years, however, computer navigation technology has made such measurements possible.

Mihalko and colleagues[2] established that soft-tissue releases on different parts of the proximal tibia have different effects on soft-tissue balancing in flexion and extension. In knees with extension varus, more releases are required on the posterior medial aspect of the tibia (the posterior oblique fibers of the superficial MCL, the posteromedial capsule, and, sometimes, the semimembranosus), whereas knees with flexion varus require more releases on the anterior medial aspect of the tibia (the deep MCL, the anterior fibers of the superficial MCL, and, sometimes, the pes anserinus attachment).[13] Consequently, soft-tissue stabilizers seem to have different functions in flexion and extension and cannot reliably be released solely in extension or flexion for optimal gap balancing during TKA.[2] Other authors, in cadaveric studies, have found that a larger amount of coronal deformity correction is achieved with more distal soft-tissue releases from the joint line.[9,14] Surgical techniques for correcting FFD include removal of prominent anterior and posterior osteophytes, posterior capsular releases, sometimes PCL sacrifices, and even gastrocnemius recession.[12]

In our study, all 14 patients with severe extension and correspondingly severe flexion varus needed not only modest posterior medial soft-tissue releases for the severe extension varus, but also modest anterior medial releases for the flexion varus. The respective soft-tissue releases were confirmed in real time with computer navigation sequentially after bony resection and osteophyte removal. With this method, we restored final postoperative alignment to within 3° of the mechanical axis (**Figure 6**). Our experience here led us to believe that, with these patients, modest anterior medial and posterior medial releases could be performed at the start of surgery, as severe extension varus (>20°) almost certainly equates to severe flexion varus (>10°). Therein lies the clinical relevance of our study. However, not all patients with severe coronal plane deformity have correspondingly severe sagittal

Table 4. **Preoperative and Postoperative Navigation Alignment Data of 15 Patients With Severe Extension Varus (≥20°)[a]**

	Preoperative			Postoperative		
Pt	Extension Varus	Flexion Varus at 90°	Fixed Flexion Deformity	Range of Motion	Varus-Valgus at Maximal Extension	Varus-Valgus at 90°
1	–24	–15	13	0.5 to 142	–1	–2
2	–23.5	–14	27.5	–1 to 139.5	0.5	–1
3	–23	–11	6	1.5 to 139.5	0	–1
4	–23	–17.5	10.5	0.5 to 122.5	1	–3
5	–22.5	–5.5	–4	–2 to 128	0	2.5
6	–21.5	–13	19	1.5 to 130	0	1
7	–21.5	–14.5	26.5	–0.5 to 122	1	–1
8	–21	–12.5	–0.5	–3 to 143.5	–0.5	–1.5
9	–21	–12.5	2.5	0.5 to 135	–0.5	–2
10	–20.5	–8.5	–2	–1.5 to 128	0	–0.5
11	–20.5	–11.5	2	–2 to 148.5	1.5	–1.5
12	–20	–9.5	–9	–2.5 to 130	–3	2.5
13	–20	–11	–7	–1 to 135	–1	1
14	–20	–9	–1.5	–2.5 to 140.5	2	2
15	–20	–14	10.5	–1.5 to 139	2	–2

[a]All values are degrees.

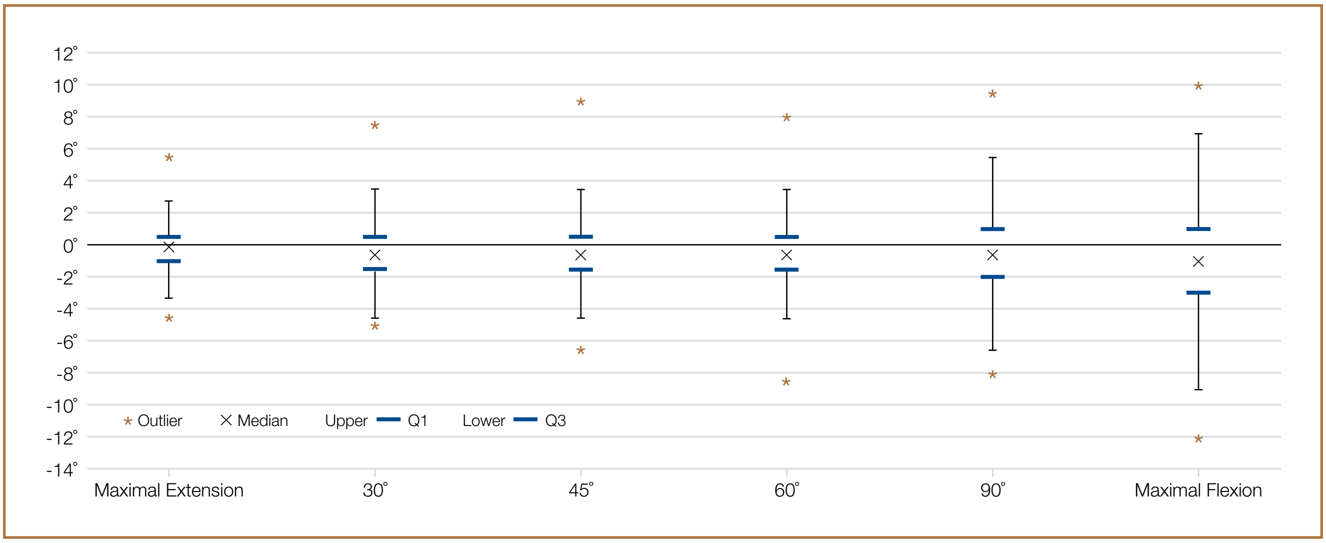

Figure 5. Box-and-whisker plot of postoperative alignment for all patients at various degrees of flexion.
Abbreviations: Q1, first quartile (25th percentile); Q3, third quartile (75th percentile).

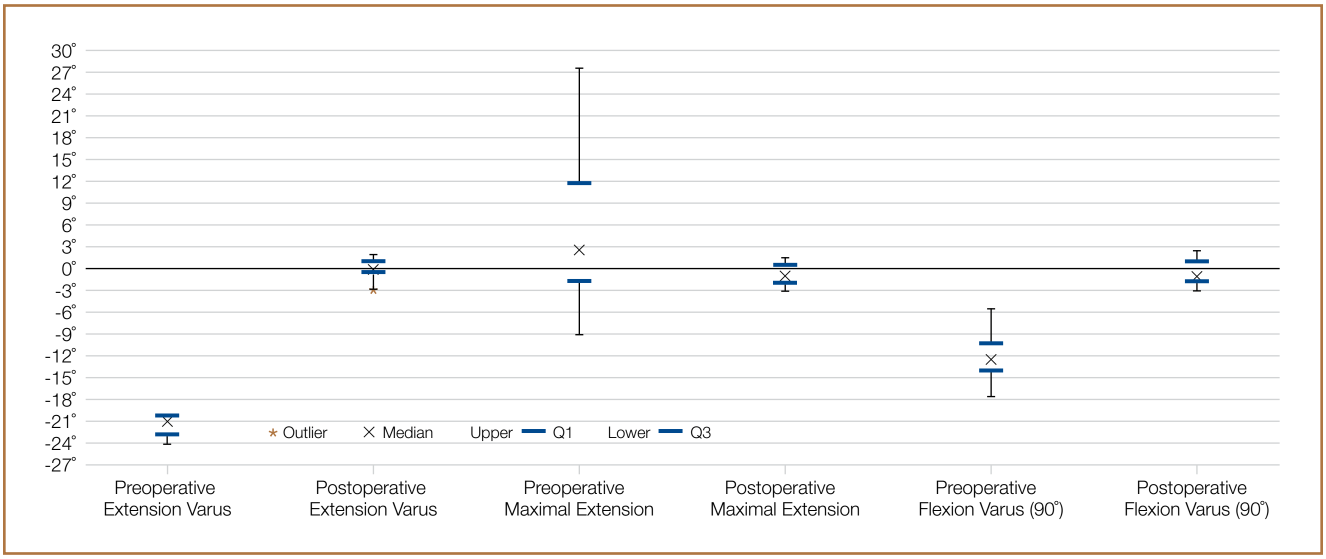

Figure 6. Box-and-whisker plot of preoperative and postoperative data for 15 patients with severe extension varus.
Abbreviations: Q1, first quartile (25th percentile); Q3, third quartile (75th percentile).

plane deformity in the form of FFD, as illustrated in our study. Therefore, not all patients with severe varus knee deformity need aggressive posterior capsular release or PCL recession to correct FFD. Some patients have mild hyperextension, which can be attributed partly to the postanesthesia effects of soft-tissue laxity. It is unclear exactly how much anesthesia contributes to this difference in sagittal alignment, though the majority of our patients had FFD. It is not our intent here to discuss the surgical techniques of soft-tissue balancing or to advocate routine use of computer navigation.

Many factors (eg, medial femoral condyle bone loss, medial tibial plateau bone loss, femur or tibia bowing, medial soft-tissue contracture) can contribute to varus malalignment. Current navigation technology cannot isolate the causes of varus alignment, and we did not intend to investigate them in this study. Our primary aim was to assess for a correlation between overall extension varus alignment and expected flexion varus. We also wanted to analyze the correlation between FFD and the coronal plane alignment, in extension and flexion, contributed by the combined bony and soft-tissue components in OA varus knees.

The strengths of this study are that it was a single-surgeon series with knee data from consecutive patients who had computer-navigated TKA. Patient data were prospectively generated from the navigation software and retrospectively analyzed. All navigation alignment was performed by a single surgeon, thereby eliminating examination bias during the time knee alignment data were being obtained. The study was adequately powered and had a large number of patients for data analysis. The authors believe that this is the first study to analyze alignment in both the coronal and sagittal plane in varus OA knees.

We acknowledge a few limitations in our study. Although several investigators have found that navigation can be used to achieve accurate postoperative alignment,[10,15,16] subtle errors may be inadvertently introduced at different points of alignment measurement. These error points include identification of visually selected anatomical landmarks; kinematic registration of hip, knee, and ankle; and intraoperative changes in the navigation environment (eg, inadvertent movement of pins or rigid bodies). In addition, different surgeons have different techniques for kinematic registration. However, the surgeries in our study were performed by the same surgeon, so this confounding factor was effectively removed. Another limitation was that navigation alignment was obtained during surgery, when patients were under anesthesia and in a supine, non-weight-bearing position, whereas routine clinical weight-bearing radiographs are taken with nonanesthetized patients and this might overestimate the deformities intraoperatively. However, all parameters were measured in the same patient under the same anesthetic effects, so this should not have affected the analyses. Most surgeons would make an intraoperative assessment of the severity of any deformity before the surgery proper anyway. Nevertheless, some authors have found that knee alignment obtained with intraoperative navigation correlated well with alignment obtained with weight-bearing radiographs.[17,18]

Conclusion

Our study results showed that, in OA varus knees, extension varus highly correlated with flexion varus. However, there was no correlation between FFD and coronal plane varus deformity.

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