Total knee arthroplasty (TKA) is a common procedure with good survivorship and functional results. Optimal results are dependent on proper osseous cuts and soft tissue balancing. Soft tissue tensioning via the polyethylene spacer thickness is an important component of soft tissue balancing. Increased thickness increases soft tissue tension and, therefore, has the potential to increase stability but decrease range of motion (ROM). Decreased polyethylene thickness may decrease soft tissue tension and has the potential to increase ROM but decrease stability.

Using computer-based navigation, the intraoperative effect of increasing and decreasing polyethylene thickness in 1-mm increments on ROM and coronal stability throughout the ROM of 35 patients was examined. It was found that increasing the polyethylene thickness by 1-mm increments had a statistically significant impact on the ability to achieve full extension but had no impact on flexion. Increased polyethylene thickness decreased coronal plane motion. Coronal plane laxity increased with increased flexion irrespective of polyethylene thickness. In this patient cohort, lateral laxity became >1° when the knee was flexed. However, medial structures prevented valgus angulation of >1° in all scenarios except when the polyethylene was diminished by 2 mm.

Changes in polyethylene thickness had an impact on the ability to gain full extension and coronal plane motion.
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total knee arthroplasty (TKA) results in good patient satisfaction and longevity.1–3 It remains a technically challenging procedure that alters the biomechanics of the knee.4 The principles of the osseous cuts are established, but the technique of rotational alignment of the osseous cuts needs to be carefully considered.5 Computer-assisted surgery can assist the surgeon in making precise osseous cuts through the navigation system.

Soft tissue balancing remains a technically demanding6,7 but important component of knee function.8 This balance is considered by assessing the medial and lateral symmetry of flexion and extension gaps and the effect of different-sized implants. Trialings allows assessment of range of motion (ROM) and stability. However, little has been written about the intraoperative effect on ROM and stability by variance in polyethylene thickness. Intuitively, it may be proposed that undersizing the spacer increases ROM at the cost of decreased stability. It may also be hypothesized that increasing the polyethylene thickness decreases ROM but increases stability. The intraoperative effect of these variances is not well described.

The purpose of this study was to consider the impact on knee stability and ROM of altering the thickness of the polyethylene insert by 1-mm increments from the polyethylene selected by the senior surgeon (D.G.C.) as part of the standard of care in TKA. The effect of polyethylene thickness on varus–valgus stability in extension and stability throughout the ROM was considered. The second outcome was ROM of flexion and extension with different insert thicknesses. The hypothesis was that increased polyethylene thickness would decrease ROM and increase stability while decreased polyethylene thickness would increase ROM at the cost of decreased stability. It was also hypothesized that the current increment of insert thickness changes of 2 to 3 mm would not be sufficient to optimize balancing. Prior to testing, a ROM of 0° to 120° and optimal varus or valgus stability of 1° or total coronal stability of 2° was defined as acceptable.

**Materials and Methods**

After Institutional Review Board ethics approval, TKA was performed in 35 consecutive knees by the senior surgeon. Outcome variables of ROM and coronal plane stability were chosen. The operating room was equipped with Stryker’s Navigation System II (Kalamazoo, Michigan), and this computer-assisted surgery platform was used to measure these outcome variables. Twenty-four women and 11 men with a mean age of 67.6±10.9 years underwent the surgery. Thirty-three patients had osteoarthritis and 2 had rheumatoid arthritis.

Each patient had the standard approach to the knee via a medial parapatellar arthroscopy. Osteophytes were removed and the cruciates released. In valgus knees, the deep medial collateral ligament was released to the midcoronal plane, but in varus knees, the soft tissue release was carried around the posterior aspect of the proximal tibia. The knee was assessed for balance, preoperative ROM, and varus–valgus stability. Component size and position were modeled using the computer-assisted surgery navigation system, and component position was selected. The distal femoral cut was made at between 5° to 7° to the anatomic axis of the femur. The tibial cut was made at 90° in the coronal and sagittal planes. Anterior and posterior distal femoral cuts were made as directed by the navigation system and verified by assessing the epicondylar axis, Whiteside’s line, and posterior condylar bony reference points. To balance the knee, soft tissue releases were made as needed. The Stryker Triathlon posteriorly stabilized femoral and tibial components were cemented into position. After allowing the cement to harden, the surgeon selected an insert thickness and assessed the knee to ensure that the ROM and stability were within his standard of care.

After the surgeon performed his standard of care balanced TKA, this polyethylene was denoted size-0 thickness. The surgeon was then blinded to visual and auditory feedback from the navigation system. After testing the size 0, the surgeon placed the −2 trial thickness in the tibial tray. The ROM and stability were reassessed. The polyethylene size was then increased by 1-mm increments to a final size 2 mm greater than the optimal polyethylene size. This resulted in a total of 5 inserts tested per knee. For ROM, terminal extension was found by holding the patient’s foot at the heel with the leg lifted off the table. The leg was allowed to fall into full extension due to gravity. Terminal flexion was found by flexing the hip to 90° and allowing the knee to fall into a position of maximal knee flexion due to gravity while holding the thigh. These measurements were repeated 3 times, and mean values were calculated.

Stability measures were conducted throughout the ROM for each polyethylene thickness. Initially, the joint was loaded with an isolated axial compressive load to determine neutral position. The knee was then brought through a ROM while manually applying a constant varus load. This was cycled 3 times. This was repeated with a valgus load. Varus and valgus angulation were measured via constant data acquisition. The mean of the 3 cycles was calculated.

Statistical analysis was performed with repeated measure analysis of variance with a significance level of .05. A repeated measures t test was used as well, using the SPSS software (SPSS Inc, Chicago, Illinois).

**Results**

Polyethylene thickness was found to have statistically significant effects on the ability to achieve full extension (P<.001) (Figure 1). Size 0 had 1° of hyperextension, whereas −2 mm of thickness had 5° of hyperextension. Adding 2 mm resulted in the ROM being 2° short of full exten-
tion. However, mean terminal flexion showed no difference secondary to polyethylene thickness ($P=0.55$) (Figure 2). The terminal flexion was 130°.

Coronal plane cumulative laxity through the ROM of 0° to 110° increased with increased flexion independent of insert thickness. Increased thickness of the insert provided significant improvement in stability, with significance achieved for each increment in insert size ($P<0.001$). The absolute increase in stability at each position diminished with increasing insert size (Figure 3). Medial-sided laxity was acceptable in all but the −2, which was above the 1° of laxity mark for entire ROM and above the 2° of laxity mark at terminal flexion. Between full extension and 110° of flexion, all other inserts were stable with <1° of medial laxity. Lateral-sided laxity was more significant than medial-sided laxity. Except in full extension, all inserts had >1° of lateral laxity throughout their ROM. Lateral laxity increased with increased flexion; the maximum varus angulation was 3.5° at 110° with the −2 insert. During the first 60° of motion, the size 0 and the increased thickness inserts had acceptable stability. However, the size 0 and increased thickness inserts also had >2° of motion at terminal flexion.

The standard of care polyethylene thickness selected by the surgeon was reviewed. With this size, 74% met the criteria of <2° of medial laxity throughout the ROM and full extension. Twenty-three percent lacked full extension via a slight flexion contracture of >0.5°. One patient had medial laxity of >2°. Of those patients who did not get terminal extension, 2 attained acceptable extension when downsized by 1 mm and 1 when downsized 2 mm. Four were able to achieve full extension with downsized inserts, but with a cost of laxity of >2°. Seventy-seven percent of patients could have tolerated a larger insert without losing full extension. Of this subgroup, 66% could have tolerated a 1-mm increase in thickness without losing full extension.

**DISCUSSION**

Total knee arthroplasty remains a complicated and technically challenging procedure. Aspects of the TKA that are critical are the osseous cuts and soft tissue balancing. Femoral cuts of 5° to 7° of valgus to the axis of the femur and cuts perpendicular to the coronal plane of the
tibial axis are commonly done.\textsuperscript{5} Despite the challenges inherent to soft tissue balancing, it is also critical to the success of the surgery\textsuperscript{9} and may be more important than the accuracy of the osseous cuts.\textsuperscript{8} Soft tissue balancing techniques are well described but remain subjective in nature. Despite intraoperative jigs and extensive expert guidance on this topic,\textsuperscript{10} changes in balance have been observed in the native and postarthroplasty groups.\textsuperscript{11} However, little has been published on the intraoperative effects on ROM and stability by altering the thickness of the polyethylene insert.

Instability is a key mechanism of TKA failure.\textsuperscript{12-14} However, what degree of instability creates a symptomatically unstable knee is unclear. Moreover, the correlation between intraoperative findings and long-term clinical findings is not available. It is known that the management of instability is challenging, must be individualized,\textsuperscript{14,15} and cannot be addressed by isolated soft tissue retensioning.\textsuperscript{12} Although instability could conceptually be treated with increased polyethylene thickness, this has controversial outcomes.\textsuperscript{16} In our patient cohort, the change in frontal plane stability increased with flexion. Lateral laxity was greater in magnitude than medial laxity. In each case, laxity increased with increased flexion. Coronal plane motion also increased with decreased insert thickness. This is a similar trend to that of the native knee of greater lateral laxity and greater laxity in flexion.\textsuperscript{17} The intraoperative findings of this cohort are the same as those found in other intraoperative studies\textsuperscript{18} but is of lesser magnitude than those seen in other reports of TKAs at \textgtr 5 years.\textsuperscript{19}

Stiffness is a common occurrence post-TKA, with a prevalence of 5\% to 6\%.\textsuperscript{10,20} Intraoperatively in this patient cohort, increasing the polyethylene thickness by 2 mm from size 0 decreased the ROM by 3\%. Decreasing the insert by 2 mm increased the ROM to 5\% of hyperextension. Increasing the insert thickness caused no change in flexion. This has also been seen in other studies.\textsuperscript{21,22} Increasing the soft tissue tension may have negative side effects,\textsuperscript{23} and this has been implicated as causal of ligamentotaxis\textsuperscript{24} secondary to the joint jack phenomenon as coined by Lombardi.\textsuperscript{25} The small changes in ROM and the improved stability indicate that increased polyethylene thickness may be an intraoperative option, especially when the surgeon wants to avoid a thin polyethylene insert.

The industry standard of at least 2-mm increments between polyethylene thicknesses may not be sufficient to optimize soft tissue balancing. In this patient cohort, 77\% could have tolerated a larger insert without losing extension; however, 66\% could only tolerate 1 additional mm because 2 mm would cause a loss of full extension. Increments of insert thickness of 1 mm in TKA equipment may be of assistance in optimizing soft tissue balancing intraoperatively.

Although the current study replicated the standard of care of intraoperative management, manual assessment of balance is a limitation to the study, as was the limited number of patients. Also, in this patient group, other factors potentially causal of stiffness in extension and increased varus–valgus motion need to be explored. The Stryker Triathlon has a constant radius femoral component. An increased posterior slope of the tibial component or undercutting the distal femur may cause increased soft tissue tension in extension despite computer-assisted surgery. A strength of the study was that a single surgeon provided his standard of care TKA. The use of computer-assisted navigation was also a strength because it allowed accurate assessment of ROM and coronal plane motion.

**CONCLUSION**

Soft tissue balancing is an important part of TKA. Although balanced flexion and extension gaps allow for soft tissue balancing, selection of an appropriate thickness of polyethylene is important. In this patient cohort, 1 mm of change in height produced significant changes in the soft tissue balance, suggesting the need to consider decreasing the incremental size of the inserts. Increasing polyethylene thickness increased coronal plane stability. Increased polyethylene thickness did not have an effect on flexion ROM but affected extension ROM. The combination of these facts suggests that tending toward an increased polyethylene thickness may provide improved stability with minimal effect on ROM.

**REFERENCES**

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