Robotic Total Knee Arthroplasty is Associated with Thinner and Less Constrained Polyethylene Inserts

Travis R. Weiner, BS
Student

Jeffrey A. Geller, MD
Associate Professor

William K. Crockatt, MD
Postgraduate Residency Fellow

Alexander L. Neuwirth
Associate Professor

Roshan P. Shah, MD
Associate Professor

H. John Cooper, MD
Associate Professor

Department of Orthopedic Surgery, Columbia University Medical Center, New York, New York

ABSTRACT

Introduction: Accurate pre-resection assessment of gap measurements during total knee arthroplasty (TKA) may reduce the need for thicker polyethylene inserts or those with higher constraint by allowing the surgeon to address potential imbalance through guiding bony resections and implant position. This study aimed to determine whether robotic assistance with pre-planning allowed for the use of thinner and less-constrained polyethylene inserts compared to conventional methods.

Materials and Methods: Records were retrospectively reviewed for 408 patients who underwent primary TKA. Patients were divided into cohorts based on the technique utilized—conventional, manual methods with a jig-based system (CM-TKA, 169 knees) versus robotic-assisted TKA (RA-TKA, 237 knees). Operative notes were reviewed for implant brand, thickness of the polyethylene insert, degree of constraint of the polyethylene insert, and whether robotic assistance was used to complete the operation. Statistical analysis was performed using Chi-square tests for categorical and t-tests for continuous variables.

Results: There were no significant differences in demographic characteristics between the RA-TKA and CM-TKA groups. Statistically significant differences were observed between cohorts in mean polyethylene insert thickness (11.0mm ± 1.3mm vs. 11.7mm ± 1.7mm, p<0.0001), rate of use of the thinnest 10mm insert (43% vs. 34%, p=0.048), rate of "outlier" insert sizes ≥14mm (5% vs. 18%, p<0.0001), and rate of constrained insert use (4% vs. 18% of knees, p<0.0001).

Conclusion: In a review of 408 consecutive TKA patients, use of robotic-assisted techniques allowed for the use of thinner polyethylene inserts, fewer "outlier" polyethylene sizes, and reduced need for constrained inserts compared to conventional, manual methods.

INTRODUCTION

Accurate gap balancing is a primary goal of total knee arthroplasty (TKA) aimed at providing stable movement of the joint and achieving a successful outcome.[1,2] Techniques to achieve adequate balancing often rely upon both bony resection and release of soft tissues. Modular polyethylene inserts must be of a minimum thickness for mechanical strength but are offered in a range of sizes, typically in 1- or 2mm increments, to allow options for the surgeon to optimally tension the gaps. Thicker inserts may be needed in those knees requiring deeper bony resections or those that undergo more significant ligamentous releases.[3] Thicker inserts may also be used more commonly when the posterior cruciate ligament (PCL) is deficient or if bony resections need to be repeated to achieve proper balancing.[4] In addition to offering inserts of varying thicknesses, many modern TKA systems also offer varus-valgus constrained inserts that can be used with primary components. These constrained inserts are often chosen by surgeons when balanced gaps cannot be achieved to their level of satisfaction, or in cases where gaps are equalized but the soft tissue constraint is insufficient.[5-7] By using a constrained insert, the surgeon may avoid persistent instability and prevent the risk of early polyethylene wear and loosening.

While undoubtedly useful to have as an option within a total knee system, there are potential downsides to using thicker or more constrained insert options. Thicker polyethylene inserts have been associated with higher rates of instability, loosening, and infection requiring revision surgery as compared to thinner inserts.[4] Constrained inserts have similarly been shown to have higher revision rates than minimally stabilized implants due to increased force transmission to the implant-polyethylene interface.[4-9] This increased stress may contribute to backside polyethylene wear in modular tibial components or premature aseptic loosening.[10]

Modern robotic TKA systems have been recently introduced as a method to both assess gap measurements and plan bone resections and alignment. These systems provide pre-resection planning capabilities, dynamic real-time tracking and measurements of patient anatomy (including flexion and extension gaps), and increased surgical precision when performing bony and soft-tissue resections. These capabilities may enable surgeons to more accurately plan components based on soft tissue tension.[11,12] Accurate pre-resection assessment of gap measurements may reduce the need for thicker implants or those with higher constraint by allowing the surgeon to address imbalance through guiding bony resections and implant position, although this has not been well-studied in the literature.[13]

The goal of this retrospective study was to determine whether robotic assistance with pre-planning allowed for the use of thinner and less constrained polyethylene inserts compared to conventional methods of TKA.

MATERIALS AND METHODS

Patient cohorts

After approval from the institutional review board, we conducted a retrospective review of consecutive patients undergoing primary total knee (TKA) by a single fellowship-trained adult hip and knee reconstruction surgeon (*author initials blinded*) between January 2018 and September 2022 using a single total knee system. Demographic variables including age, gender, and medical comorbidities were collected from the electronic medical record. Operative notes were reviewed for thickness of the polyethylene insert, degree of constraint of the polyethylene insert, and whether robotic assistance was used to complete the operation. Patients were divided into two cohorts based on the technique utilized—conventional manual methods with a jig-based system (CM-TKA) or robotic-assisted TKA (RA-TKA). All patients received a Zimmer Persona® knee implant (Zimmer Biomet, Warsaw, Indiana). RA-TKAs were performed using the ROSA® Total Knee System (Zimmer Biomet, Warsaw, Indiana) (Fig. 1). Any patients without information related to polyethylene insert thickness or type of insert implanted were excluded from analysis.

Figure 1. ROSA® Total Knee System.

Surgical technique

Surgical techniques prior to bony cuts were consistent between the manual and robotic cohorts. Procedures were performed using an anterior midline incision and medial parapatellar arthrotomy. A medial release along the proximal tibia was performed, the extent of which varied by the deformity at the discretion of the surgeon, with valgus knees receiving a smaller medial release and fixed varus knees receiving a larger medial release as part of the exposure. The anterior (ACL) and posterior cruciate ligaments (PCL) were both resected, and the tibia underwent a complete anterior subluxation. All visible osteophytes were removed.

In the CM-TKA cohort, distal femur resection was performed using an intramedullary guide with the distal cutting block set at 5° of valgus relative to the canal. The proximal tibial resection was then performed with an extramedullary cutting guide, aiming for a neutral mechanical axis, 0 to 3° of posterior tibial slope and enough bony resection depth to eventually fit a 10mm or 11mm polyethylene insert. Once the distal femoral and proximal tibial resections were performed, a spacer block and drop rod were used to confirm adequate bone resection, balance, and tibial alignment. Inadequate resection or undesired alignment were treated with additional bony resection, and unbalanced gaps were treated with medial or lateral soft tissue releases. Once acceptable extension balance was achieved, a four-in-one femoral guide was placed using an anterior referencing system set at 3° of external rotation from the posterior condylar axis and adjusted as needed to achieve a balanced flexion gap.

In the RA-TKA group, percutaneous self-drilling, self-tapping pins were inserted into the femur and tibia and tracking arrays were attached. Registration was performed following the manufacturer recommended technique, using anatomic landmarks without preoperative image guidance to define the coronal, sagittal, and axial planes of the tibia and femur and the surfaces of the distal femur and proximal tibia. The knee was then brought through a dynamic ROM with stressed varus and valgus forces applied at or near full extension and at 90° of flexion. This provided quantitative information, to the nearest 0.5mm, about the maximal medial and lateral compartment laxity in flexion and extension. This soft tissue laxity information was used to plan and modify the angle and depth of bony resections with the pre-resection goal of balanced gaps within 1.0 to 1.5mm (Fig. 2a and b). The robotic arm was then used to complete these pre-planned femoral and tibial bone cuts.

Regardless of how the bony resections were performed, in both the CM- and RA-TKA groups, trial components were placed after these bony resections were completed. Flexion and extension gaps were then assessed by the surgeon with a goal of balanced flexion and extension gaps (approximately 1 to 2mm of laxity on medial and lateral sides). If necessary, the thickness of the tibial insert was increased or soft tissues were again balanced to the satisfaction of the surgeon before final components were implanted. If balance could not be achieved with a minimally constrained bearing, a varus-valgus “constrained posterior stabilized” insert was used.

Figure 2a and b. Planning and modification of the angle and depth of bony resections using the ROSA Total Knee System.

Statistical analysis

Statistical analysis was carried out using SPSS software (version 28.0, SPSS Inc., Chicago, Illinois). Chi-square tests were used to examine differences between the RA-TKA and CM-TKA groups for categorical variables such as gender and rates of insert usage and t-tests for continuous variables such as age and polyethylene insert thickness. All p-values were for two-sided tests, and p-values <0.05 were considered statistically significant.

RESULTS

Records were reviewed for 408 consecutive patients who met inclusion criteria. Two patients who did not have recorded information for polyethylene insert thickness were excluded from this study, leaving a total of 406 patients with 237 in the RA-TKA cohort and 169 in the CM-TKA cohort. There were no significant differences in demographic characteristics, including gender and age, between the two groups (Table I).

Table I
Demographic characteristics

N (%)	N 406	RA-TKA 237	CM-TKA 169	p-value
Sex				0.770575
Men	148 (36.5%)	85 (35.9%)	63 (37.7%)	
Women	258 (63.5%)	152 (64.1%)	106 (62.3%)	
Age (yrs)	—	66.65 ± 10.06	68.1 ± 8.9	0.1341

Table II
Comparisons in polyethylene insert average thickness between RA-TKA and CM-TKA groups

All Patients (n=406)	RA-TKA	CM-TKA	p-value
Average Thickness (mm)	11.03 ± 1.26	11.67 ± 1.68	<0.0001

Table III
Rate of usage of the thinnest insert available (10mm) between RA-TKA and CM-TKA groups

All Patients (n=406)	RA-TKA	CM-TKA	p-value
# of Thinnest Inserts			0.047911
Non-thinnest/Insert >10mm (n=246)	134 (57%)	112 (66%)	
Thinnest/Insert = 10mm (n=160)	103 (43%)	57 (34%)	

Table IV
Rate of usage of "outlier" inserts (≥14mm) between RA-TKA and CM-TKA groups

All Patients (n=406)	RA-TKA	CM-TKA	p-value
# of Outliers			0.000018
Outliers/Insert ≥14mm (n=43)	12 (5%)	31 (18%)	
Non-outliers/Insert <14mm (n=363)	225 (95%)	138 (82%)	

Table V
Rate of usage of constrained inserts between RA-TKA and CM-TKA groups

All Patients (n=406)	RA-TKA	CM-TKA	p-value
Poly Type			<0.00001
Constrained (n=41)	10 (4%)	31 (18%)	
Non-Constrained (n=365)	227 (96%)	138 (82%)	

We found statistically significant differences between the RA-TKA and CM-TKA cohorts in regard to mean polyethylene insert thickness (11.0mm ± 1.3mm vs. 11.7mm ± 1.7mm, p<0.0001) (Table II), more frequent use of the thinnest available polyethylene insert (43% vs. 34%, p=0.048) (Table III), and less frequent use of "outlier" polyethylene insert sizes ≥14mm (5% vs. 18%, p<0.0001) (Table IV), respectively. Additionally, we found a statistically lower rate of utilization of constrained inserts (4% vs. 18%, p<0.0001) among robotic-assisted TKA when compared to the conventional TKA cohort (Table V).

DISCUSSION

Overall, we found that robotic-assisted techniques of total knee arthroplasty allowed for the use of thinner polyethylene inserts and fewer constrained inserts compared to conventional manual methods. We also found that the use of robotic methods reduced the number of "outlier" polyethylene sizes, producing a more predictably balanced knee. Our results are consistent with the current literature comparing robotic to conventional TKA. Nam et al. similarly found a significantly reduced number of insert size "outliers" (0%, 0 of 154 knees) when using the Stryker MAKO system (Mahwah, New Jersey) during RA-TKA as compared to conventional methods (2.6%, 4 of 154 knees); however, the authors did not find a difference in ratio of polyethylene insert thickness among the 9mm, 11mm, 13mm, and 16mm options used in their study (p=0.321).[14]

The current literature is mixed regarding the true influence of insert thickness on outcomes. In a registry review of 185,539 TKAs over a 14-year period, Khan, et al. found a five-times increased rate of revision surgery in knees with polyethylene thickness ≥15mm compared to those with inserts <10mm. Additionally, they showed a four-times higher rate of early revision for loosening, instability, and infection compared to knees with inserts that were 11 to 14mm.[4] Khan's findings support an earlier study by Berend et al. which similarly demonstrated higher failure rates in knees using insert thickness ≥16mm versus those <14mm (2.5% vs. 0.8%, p<0.0001). The authors suggest the higher failure rates with thicker inserts, particularly due to instability, may be related to surgical variables that require deeper tibial resection or correction of deformity with ligamentous releases.[3]

Yet other retrospective studies have found no differences in clinical outcomes or revision rates related to polyethylene insert thickness. Greco et al. showed no significant functional differences or need for revision procedures between two cohorts with inserts >14mm versus ≤14mm at a minimum two-year follow up. They also found no failures for instability or aseptic loosening among the larger thickness cohort despite requiring thicker tibial resection compared to those knees when a thinner insert is used.[15] In a comparison of "thin" (9.9 [±1.5]mm) and "thick" insert (14.6 [±2.2]mm) cohorts among patients undergoing staged bilateral TKAs, Garceau et al. found no significant difference in change in Knee Severity Score nor range of motion at a mean four-year follow up. They also found no correlation with increased revision rates for loosening, instability, or stiffness.[16]

The literature is similarly mixed on the true effects of constrained liners. Constrained implants have historically been reported to have higher revision rates than minimally stabilized implants due to increased force transmission to the implant-polyethylene interface,[4-9] particularly if not used in conjunction with stemmed extensions. This increased stress is thought to contribute to backside polyethylene wear in modular tibial components and premature aseptic loosening.[10] Stem extensions also come with their own disadvantages of increased operative complexity and financial cost, instrumentation of the medullary canal, and reduced bone stock if requiring future revision.[17,18] However, in a retrospective 2:1 matched cohort of primary TKAs comparing posterior stabilized (PS) to varus valgus constrained (VVC) implants without stem extensions, Stockwell et al. reported similar short and midterm survivorship, rate of radiographic loosening, and overall clinical satisfaction.[18] It is the preference of the senior author to utilize as many minimally constrained liners as possible and constrained liners only if adequate balance cannot be achieved.

While further research is required to determine the true effect of polyethylene insert size and constrained insert type on revision rates and functional outcomes, the use of robotic-assisted methods in this study was shown to reduce the number of "outlier" insert sizes used. The literature has shown robotic-assisted TKA to produce significantly more accurate bone cuts and implant positioning,[14,19,20] as well as improved compartment balancing compared to conventional TKA,[21] which may ultimately reduce the need for thicker and more highly constrained implants.

This study has several limitations. First, as this is a retrospective study, we were limited to only the information documented in the electronic medical record and internal departmental registries. Second, as full-length standing radiographs were not available for the majority of patients, we were unable to assess and correlate pre- and postoperative radiological data such as limb axis and implant position to the polyethylene insert selected. Third, this is a single surgeon series, and the results may not be generalizable to other orthopedic surgeons. Finally, we did not correlate these findings to patient-reported outcome measures nor incidence of complications/need for revision procedures. As such, we are unable to describe the true clinical significance of these findings; however, this may be an avenue for further research.

CONCLUSION

In a review of 408 consecutive total knee arthroplasty patients, use of robotic-assisted techniques allowed for the use of thinner polyethylene inserts, fewer "outlier" polyethylene sizes, and reduced need for constrained inserts compared to conventional, manual methods. **STI**

AUTHORS' DISCLOSURES

The authors have no conflicts of interest to disclose.

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