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The Efficacy of Robotic-Assisted Total Knee Arthroplasty Compared to Manual Total Knee Arthroplasty in Regards to Accuracy, Operative Time, and Patient Outcome

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Purpose:

Knee replacement is a frequently performed joint surgery, with more than one million procedures performed annually.[1] The latest innovation in Total Knee Arthroplasty (TKA) involves the utilization of robotics to enhance patient outcomes. This review aims to evaluate the accuracy, operative time, and patient outcomes of Robotic Assisted TKA in comparison to conventional TKA to determine the most effective technique for overall patient care.

Abstract:

Objectives:

This review evaluates the literature comparing Robotic-assisted and Conventional Knee Arthroplasty based on accuracy, operative time, and patient outcomes. It aims to determine the potential of robotic-assisted surgeries in orthopedics and other surgical fields to provide guidance to medical professionals on best practices in Knee Arthroplasty.

Methods / Evidence Acquisition:

This study conducted a search for evidence primarily on two databases: PubMed and Web of Science, with two additional articles found in the National Library of Medicine. The search utilized the term "Robotic Assisted Total Knee Arthroplasty" matched with various Mesh terms. Only articles published between 2018 and the present were included for evidence collection. The selection order of study designs preferred randomized controlled trials, retrospective cohort studies, literature reviews, and one meta-analysis. The extracted information from each article focused on accuracy, operative time, and patient outcomes.

Results and Discussion / Evidence Synthesis:

The measurement of the postoperative Hip-Knee-Ankle (HKA) in comparison to the preoperative plan demonstrated significantly greater accuracy in Robotic Assisted Total Knee Arthroplasty (RATKA) than in conventional TKA. Furthermore, the number of outliers was significantly less in RATKA than in conventional TKA. Conversely, the operative time was significantly longer in RATKA than in conventional TKA. Patient outcomes, including estimated blood loss, length of stay, complications, the number of revision surgeries, and C-Reactive Protein (CRP), did not differ significantly between the two techniques; however, estimated blood loss, length of stay, and CRP displayed a trend toward better outcomes in RATKA. The results of the analysis revealed a clear advantage in terms of cost effectiveness for RATKA

Conclusions:

RATKA demonstrated greater implant position accuracy and consistency compared to conventional TKA, whereas conventional TKA exhibited a significantly shorter operative time than RATKA. Since no other significant differences in patient outcomes were discovered besides cost, whether to utilize RATKA or conventional TKA should depend on the individual patient. Patients who require higher accuracy levels for optimal outcomes should undergo RATKA. Conversely, patients at higher risk for intraoperative complications as surgery duration increases should opt for conventional TKA.

Introduction:

Advanced knee osteoarthritis is one of the primary indications for TKA. The National Health and Nutrition Examination Survey reports that 37% of individuals aged 60 and older are afflicted with knee osteoarthritis, which more frequently affects women than men.[2] Osteoarthritis is a joint disease characterized by whole knee joint degeneration, with cartilage loss being one of its defining features.[2] While disease progression rates vary by the individual, pain, stiffness, limited joint mobility, and muscle weakness are the common symptoms of knee osteoarthritis.[2]

Initial treatment for knee osteoarthritis includes dietary and exercise interventions, as well as weight loss for those who are overweight or obese.[2] If these interventions fail, pharmacological treatment such as nonsteroidal anti-inflammatory drugs (NSAIDs), acetaminophen, duloxetine, and tramadol may be considered.[2] Intra-articular glucocorticoid injections may also be administered.[2] When conservative management fails to control advanced knee osteoarthritis, knee replacement surgery is the definitive treatment.[2]

Conventional TKA was first performed in the early 1800s using ivory prostheses, which were later replaced in the 1930s with metal implants due to poor outcomes.[3] In the 1970s, a breakthrough was made in TKA prosthesis design that more closely replicated the natural joint of the knee and yielded better outcomes.[3] The current standard for TKA surgery involves manual cutting and prosthesis alignment by the lead surgeon, and has resulted in improved quality of life, pain relief, and increased functionality for patients.[4] However, manual alignment is subject to the potential for human error, even in the most skilled surgeons.

Although TKA is a generally effective procedure, approximately 20% of patients express dissatisfaction with the results due to various personal reasons.[5] This literature review examines the standard approach to TKA and evaluates the evidence supporting the potential benefits of robotic-assisted TKA surgery. Robotics technology was first introduced in the 1980s to improve the accuracy and precision of prosthesis alignment, reduce patient complications, and enhance patient outcomes.[6] Compared to previous techniques, RATKA is unique in that it focuses on improving preoperative planning and intraoperative dynamic referencing through the use of preoperative CT scans and a computer program to determine optimal cuts.[6] Additionally, the robotic aspect includes a haptic feedback-controlled system that provides real-time guidance to surgeons, potentially allowing for more precise cuts while protecting vital soft tissue structures.[6]

This review evaluates the differences in accuracy and precision, operative time, and patient outcomes between conventional TKA and RATKA. Accuracy will be assessed based on prosthesis alignment and consistency of each technique. The postoperative Hip-Knee-Ankle radiographic angle measurements and angle outliers will be analyzed as two subcategories. Operative time will be quantified by mean operative time, and the learning curve of RATKA will be assessed to determine the potential for reducing operative time with experience. Finally, patient outcomes, including estimated blood loss, length of hospital stay, complications, revision surgeries, serum C-Reactive Protein levels, and cost effectiveness will be evaluated as a crucial component of treatment to improve patient results and prognosis. This review seeks to contribute to the continuous efforts to improve patient care by providing valuable information to healthcare providers regarding the potential of RATKA as a promising technique for knee replacement surgery. The results of this review may have significant implications for the future of knee replacement surgery, ultimately benefiting patients through improved outcomes.

Background of techniques:

Conventional manual alignment technique

Although there are a few different approaches to conventional TKA, each with its own indication, the most commonly utilized is the medial parapatellar approach.[4] Once the arthrotomy is complete, the patella is everted, and the knee is flexed and dislocated.[4] Subsequently, the tibia or femur is resected first, depending on the surgeon's preference.[4] To stabilize the bone resection, a distal femoral intramedullary jig is inserted via an opening created in the intramedullary canal.[4] The femoral resection is preoperatively planned based on the patient's x-rays and is usually between five to seven degrees of valgus.[4] The next step is the proximal tibia resection, which is stabilized using either an intramedullary or extramedullary guide.[4] The cut is made perpendicular to the tibial axis, with the tibial rotation set to the medial one-third of the tibial tubercle and a point slightly medial to the center of the ankle joint.[4] The extension gap is assessed, and on full extension, a spacer is placed in the joint, and the overall balance is assessed using an alignment rod.[4] The flexion gap is made by anterior, posterior, anterior chamfer, and posterior chamfer cuts to ensure the flexion gap is rectangular and the balancing is correct while ensuring the collateral soft tissue structures remain unharmed.[4] A cut perpendicular to the tibial external axis is made to create the intercondylar notch, and trial implants are impacted, followed by ROM testing and then the real implants are placed.[4] Once satisfactory, wound closure is performed.[4]

Robotic Assisted alignment technique

The approach to the RATKA is similar to that of conventional TKA. However, prior to bone resection, temporary bone pins are placed into the femur and the tibia.[7] Two distal femoral and proximal tibial pins are placed in the diaphyses and connected to arrays that relay information to a computer program.[7] The purpose of the pins and arrays is to relay to the computer where the femur and tibia are in space. The next step is to map the range of motion, bony articular surface, and mechanical axis alignment.[7] This allows the computer to get a baseline level of where the various structures of the knee are and their limitations. The computer can then plan out the required bone resections to create an optimal surface for the implant as well as optimal gap balancing. These resections can also be fine-tuned to correct the soft tissue and ligament balance.[7] A burr attached to the robotic arm's end allows the surgeon to guide the arm to make the femoral and tibial resections.[7] Although the surgeon has control over the robotic arm for these resections, through a haptic feedback mechanism, the robotic arm will prevent the surgeon from guiding the arm too far from the preoperatively planned resections. This helps protect the soft tissue structures on either side of the resections. Once resections have been completed and confirmed by the computer program, the prosthesis can be trialed.[7] The rest of the procedure is similar to the conventional technique, where ligamentous balance and tension are tested.[7] However, the robotic system continues to assist by quantifying the balance and tension amounts.[7] The medial and lateral gaps are therefore able to be minimized and maximized to ensure the best possible balance is achieved.[7]

Methods:

This study was conducted by searching two prominent databases, namely PubMed and Web of Science, with a primary focus on patients undergoing TKA. The research aimed to explore articles that have compared RATKA to the conventional technique. The main intervention search utilized was “Robotic Assisted Total Knee Arthroplasty,” while the outcomes search included various Medical Subject Headings (MeSH) terms such as “operative time,” “outcomes,” “surgical blood loss,” “cost”, and other outcome-related terms such as “accuracy” and “mechanical axis.” Furthermore, the search used the term “osteoarthritis” to retrieve a single article. An additional database, the National Library of Medicine, was also utilized to retrieve two articles. The study's exclusion criteria allowed only articles published in the past five years for evidence collection to ensure the most up-to-date information acquisition. A search of the main intervention on PubMed resulted in 637 outcomes. After selecting the randomized controlled trial filter, 23 results remained. The Meta-Analysis filter resulted in 19 articles. Additionally, the Web of Science searches combined the primary intervention with one of the MeSH outcome terms, which led to the selection of nine papers from PubMed and eleven papers from Web of Science. Overall, the search retrieved 22 articles, including a meta-analysis, literature reviews, randomized controlled trials, and retrospective cohort studies, which fulfilled the study's inclusion criteria.

Evidence Synthesis:

RATKA will now be compared to Conventional TKA regarding accuracy and precision, operative time, and patient outcomes. The two study arms will be evaluated in this order. The most recent body of evidence in the orthopedic knee surgery domain will be utilized to determine the efficacy of each technique.

Accuracy and Precision

Hip-Knee-Ankle-Angle

The angle to be discussed under accuracy is the Hip-Knee-Ankle-Angle (HKA). The HKA angle is a measure between the femur's and tibia's mechanical axes. In a study by Li et al., a randomized controlled trial of HURWA robotic-assisted TKA was compared to conventional TKA, where the former technique yielded a significant difference in HKA angle averaging 1.801° varus and an average HKA angle of 3.017° for the conventional TKA group (p=.0207).[8]

Bataillier et al. agreed with these findings in their retrospective matched-pair comparative study, which found the average HKA angle from their robotic-assisted group to be 177.4° and the average HKA angle from the conventional group to be 175.7°, a statistically significant difference (p=.022).[9] Another study by Thiengwittayaporn et al. corroborated these findings in their prospective, randomized controlled study where they found the postoperative mean HKA angle for the robotic-assisted group to be 178.4° and the conventional TKA group to have a mean HKA angle of 177.9°, with a p<.009 making the difference statistically significant.[10] A prospective randomized controlled study by Kayani et al. further supported these findings, reporting the planned limb alignment to be an average of 3.1° varus in the conventional TKA group and an average of 1.2° varus in the robotic-assisted group (p<.001).[11] Another supporting study was conducted by Vaidya et al. as a prospective randomized controlled study, yielding an average of 1.8° in the RATKA group and 3° in the conventional TKA group.[12] The difference in these averages resulted in p=0.019, showing a statistical significance between the two study groups.[12] One more study by Xu et al. found evidence to agree that robotic-assisted TKA was more accurate according to postoperative HKA angle measurements in a retrospective cohort study.[13] The HKA angle was found to be on average 178.7° in the robotic-assisted cohort and 177.8° in the conventional TKA cohort (p=.041).[13] This study's findings must be followed with caution because this study was conducted on Chinese patients.[13] Therefore, we must be careful with generalizing these findings to American citizens due to genetic and cultural differences.

Although the six previous studies found statistical significance, not all were as homogenous. A study by Choi et al. found no significant difference when they compared the difference in postoperative HKA angle to the preoperative plan between the two groups: functionally aligned robotic-assisted TKA and mechanically aligned manual TKA.[14] They conducted a retrospective cohort study based on a database containing prospectively collected data.[14] The mean difference of HKA angle in the robotic group is 0.3° varus, and the manual group is 0.8°.[14] The p-value was determined to be nonsignificant.[14] Caution should be exercised when comparing the results of this study to those of other studies, as the additional variable of functional alignment versus mechanical alignment may not be present in those studies. In a separate study from the previously mentioned by Xu et al., the findings of this study by Xu et al. agree with Choi et al., where they did not find a statistical significance between the two study groups regarding the HKA angle.[15] In comparison to the previous retrospective cohort study by Xu et al., this study was a prospective randomized controlled trial.[15] The HKA angle was found to be an average of 178.2° in the RATKA group and 177.4° in the conventional TKA group ($p=.052$).[15] Although this p-value does not indicate significance, since it is so close to the cutoff, the strength of this evidence should not be weighed more heavily than other studies with more significant p-values. Another study by He et al. agrees with Choi et al. and Xu et al. in their retrospective cohort study of the "Skywalker" robot.[16] They found that their conventional TKA group had a postoperative average HKA angle of 178.3° and the RATKA group had an average postoperative HKA angle of 178.5°.[16] The resultant p-value was 0.209, indicating nonsignificance.[16] Since this study was conducted using a new robot called "Skywalker" rather than one of the more popular robots, this factor must be considered when comparing these results to other studies of RATKA.

Of the previous nine studies, six found significant differences in their respective study groups on the statistic of HKA angle, and three found no significance. Accuracy is essential for TKA surgery because it indicates how well the preoperative plan was executed.

Outliers

An outlier encompasses a postoperative radiographic measurement that deviates more than 3° from the preoperative plan, indicating that the surgery did not achieve the goal with sufficient accuracy. In a meta-analysis of 18 studies by Onggo et al., 2234 robotic TKA (rTKA) and conventional TKA (cTKA) were reviewed, wherein they investigated five angles of the knee. They found a statistical difference between the number of outliers between rTKA and cTKA in terms of the angles HKA, femoral coronal, and tibial sagittal in favor of rTKA.[6] Mechanical axis outlier events occurred 61 total times resulting from rTKA in the studies reviewed and 143 times from cTKA (OR .34, 95% CI 0.20-0.58, p<.0001).[6] The femoral coronal outlier events occurred 53 times from rTKA and 103 times from cTKA (OR 0.47, 95% CI 0.29-0.75, p=0.002).[6] Lastly, the tibial sagittal angle was found to have 88 outlier events from rTKA and 159 events from cTKA (OR 0.35, 95% CI 0.15-0.81, p-0.01).[6] The other two angles, femoral sagittal and tibial coronal, were found not to have a significant difference in outlier events indicated by p=0.08 and 0.19, respectively.[6] A study by Batailler et al. found similar results for the HKA and tibial coronal angle outliers but not for femoral coronal angle outliers.[9] A statistical significance was found for the HKA angle (p=.003); however, no significance was found for the tibial coronal outliers (p=0.36).[9] Where the findings differ in Batailler et al.'s study from Onggo et al. is that Batailler et al. did not find a significant difference between RATKA and conventional TKA regarding femoral coronal alignment outliers (p=0.087).[9] However, all significant differences were in favor of RATKA, which is in agreement with Onggo et al.'s study. A study by Thiengwittayaporn et al. keeps in tandem with this theme. They found that the HKA, coronal tibial, sagittal tibial, and sagittal femoral angles were all statistically significant in terms of outliers in favor of RATKA (p=0.035, p=0.027, p=0.002, and p<.001, respectively).[10] The study did not find a statistically significant difference in the coronal femoral angle outliers ($p=0.179$).[10] One more study that agrees with the previous studies is by Choi et al.[14] They found a significant difference in the percentage of outliers in the femoral coronal and tibial sagittal angles, as shown by $p=0.017$ and 0.015, respectively.[14] The other three angles did not show any significant difference.[14]

The number of outliers that occurs from a TKA surgery is a good predictor of the consistency of a technique. A technique that consistently deviates from the preoperative plan by a large margin is not the most effective care.

Operative Time

Mean operative time

The mean operative time is essential to any surgery due to the multitude of factors and associated risks that may progressively escalate with each minute of prolonged surgery. In a meta-analysis by Onggo et al., six studies were reviewed specifically for mean operative time.[6] The result of that study was that the mean operative time for RATKA was, on average, much longer than conventional TKA ($p=0.006$).[6] Xu et al. agreed with this conclusion in their study, finding that the average operative time for RATKA (154.3 minutes) was longer than conventional (115.2 minutes).[15] This was associated with a $p<.001$ indicating statistical significance.[15] Batailler et al. continue with this theme, finding the average operative time for RATKA (169 minutes) to be longer than conventional TKA (140 minutes).[9] This was found to have a higher level of statistical significance due to a p-value of $<.0001$.[9] Another study that agrees with the previous three is by Smith et al. In their prospective cohort study, the difference in average operative time between RATKA (96 minutes) and conventional TKA (86 minutes) was determined to be statistically significant in favor of conventional TKA ($p<0.01$).[17]

Not all studies reviewed agreed with the theme that RATKA was associated with a longer mean operative time. For example, a study by Kayani et al. did not find a statistical significance in the difference in operative time between RATKA and conventional TKA.[11] Mean operative time for conventional TKA was 61.4 minutes, and RATKA was 62.4 minutes.[11] Although the time was less for conventional TKA, the p-value was 0.621.[11] Another study by He et al. agreed with Kayani et al. They found the difference in average operative time for RATKA (128.4 minutes) and for conventional TKA (119.5 minutes) to be nonsignificant ($p=0.419$).[16] Operative time should be minimized as much as possible to lessen the risk to the patient.

Learning Curve

Several articles have noted a potential learning curve in reducing operative time for RATKA compared to conventional TKA. With more experience gained by the surgeons, the operative time seemed to decrease, potentially to a level akin to conventional TKA. Thiengwittayaporn et al. found that when all cases they researched were compared, the average operative time for RATKA and conventional TKA was 70.1 minutes and 61.9 minutes, respectively.[10] The resultant p-value indicated that conventional TKA was significantly faster than RATKA ($p<0.001$).[10] However, the researchers of this study also decided to stratify the first 10 cases and the last 10 cases for RATKA.[10] When each group was compared to all conventional TKA cases, similar results were seen for the first 10 cases.[10] Average operative time for RATKA was 95.0 minutes and significantly slower than conventional TKA ($p<0.001$).[10] However, when the last 10 cases of RATKA were compiled, the average operative time was determined to be 66.6 minutes.[10] This resulted in a nonsignificant p-value, indicating that the times between RATKA and conventional TKA were comparable.[10] Additionally, the learning curve was determined to be seven cases of experience.[10] Marchand et al. found results that resembled the study by Thiengwittayaporn et al. In this non-randomized cohort study, a high-volume surgeon performed RATKA cases, and the operative times were recorded at one month, six months, and one year.[18] The operative times were compared to a manual cohort to determine significance.[18] The mean operative times at one month, six months, and one year were 81 minutes, 65 minutes, and 62 minutes, respectively.[18] The p-value for the six-month operative time indicated nonsignificance ($p=0.12$).[18] However, the one-year p-value indicated statistical significance ($p=0.008$).[18] This study showed that the operative time continuously decreases to a statistically significantly lower point than conventional TKA over a one-year period.[18] However, the findings of this study should be interpreted with caution since it was a nonrandomized study by a single surgeon. One more study by Sodhi et al. mirrors the results of the previous two studies by following two surgeons that each completed cohorts of 20 cases at a time.[19] The first surgeon's first cohort had an average operative time of 81 minutes, statistically significantly slower than the manual TKA ($p<0.005$).[19] However, the first surgeon's last cohort was an average operative time of 70 minutes which proved to have a nonsignificant difference from the manual TKA cohort.[19] The second surgeon found similar results where their first cohort of 20 cases compared to manual TKA was significantly slower ($p<0.05$).[19] Their last cohort, however, in tandem with the first surgeon, was found not to have a significant difference in operative time from the manual cohort ($p>0.05$).[19]

The demonstration of a learning curve hints at the potential for reduced operative time with experience. If incorporated into education, perhaps the learning curve could be eliminated.

Patient Outcomes

Estimated Blood Loss

The estimated blood loss (EBL) that occurs during surgery is an important aspect of the performance of a procedure because EBL should be minimized as much as possible for the patient's benefit. In a meta-analysis by Onggo et al., two studies were reviewed for their data on EBL.[6] They found a tremendous statistical significance where RATKA had a much lower EBL than conventional TKA ($p<0.00001$).[6] Xu et al. agree in one of their studies that favors RATKA.[13] They found in their Mako-assisted TKA group that the average EBL (496.9 ml) was significantly less than in their conventional TKA group (773.0 ml) ($p<0.001$).[13] One more study that agrees in favor of RATKA is by He et al.[16] Their analysis found the average EBL of RATKA to be significantly less than conventional TKA, with values of 192.3 ml and 203.7 ml, respectively ($p<0.05$).[16]

However, a study by Batailler et al. found no significant difference.[9] Their study used two methods to calculate the EBL of their study groups.[9] They calculated Bourke's formula at one and three days postoperatively ($p=0.7$ and $p=0.25$, respectively) and Camasara's formula overall ($p=0.5$).[9] None of these values indicated statistical significance.[9] In another study by Xu et al., similar results were found.[15] Difference in average intraoperative blood loss for RATKA (933 ml) and conventional TKA (863 ml) did not indicate significance ($p=0.519$).[15]

The efficiency of the surgery can be reflected in the estimated blood loss amount. Therefore, a technique that better minimizes EBL would be superior to others in this regard.

Length of Stay

The length of stay (LOS) is one of the most notable outcomes for the patient. In a study by He et al., the average LOS for the RATKA group was 8.2 days, whereas the average LOS for the manual TKA group was 9.3 days.[16] The p-value was 0.006 indicating a significant difference in which RATKA leads to a shorter recovery period postoperatively.[16] Smith et al. agree with this conclusion in their study, where they found the difference in average LOS for the RATKA group (2.1 days) and manual TKA group (2.6 days) to be statistically significant (p=0.0004).[17]

Xu et al. however, did not find a significant difference in their research.[15] The average LOS of RATKA and conventional TKA in their groups were 9.1 days and 8.4 days, respectively (p=0.175).[15] Batailler et al. similarly did not find a significant difference.[9] Their average LOS of robotic and conventional TKA groups were 5.1 and 4.9 days, respectively (p=0.71).[9] One more study that shared these findings was by Fontalis et al.[20] The average LOS of RATKA (76.4 hours) and conventional TKA (78.6 hours) did not find statistical significance (p=0.693).[20]

Many patients will equate the LOS after surgery to the procedure's success. Decreasing the LOS can improve patient satisfaction and outcomes.

Complications

Postoperative complications are a crucial aspect of surgery as they can significantly affect the patient's recovery. In a meta-analysis by Onggo et al., 10 studies were reviewed intentionally for complications.[6] The total number of events from robotic TKA was 51, and the total for conventional TKA was 43.[6] Although robotic TKA was seen to have more events, the difference was nonsignificant, with a p-value of 0.80.[6] Held et al. agrees with Onggo et al. because they found from a sample of 221 TKAs, the difference in events of patients with any complications in conventional TKA (19) and RATKA (17) were nonsignificant (p=0.719).[7] Xu et al. recorded the postoperative complication of Deep Vein Thrombosis (DVT).[15] At 30 days postoperatively, the number of DVTs between RATKA (10) and conventional TKA (11) was nonsignificant (p=0.736).[15] Two studies by Batailler et al. and Kayani et al. uniformly found that neither of their study groups had any postoperative complications.[9,11] Smith et al. also reported similar postoperative complications in their groups.[17] Postoperative complications are an important ramification that must be reduced since they can impart negative outcomes.

Revisions

Revision surgery is when the first surgery did not successfully implement the intended changes, necessitating a second surgery. In a meta-analysis by Onggo et al., four studies were reviewed for revision surgeries.[6] Onggo et al. found that the difference in the total number of revision surgeries completed by robotic TKA (7) and conventional TKA (11) in those studies was found to be statistically nonsignificant (p=0.28).[6] Smith et al. found a similar result to Onggo et al., albeit with different data.[17] Smith et al. too found a nonsignificant difference; however, this was due to neither of his groups having any revision surgeries.[17] One more study that agrees with the previous two is by Held et al.[7] Total reoperations between RATKA (5) and conventional TKA (6) were not statistically significant (p=1).[7] Revision surgeries indicate that the initial surgery was insufficient and therefore a good technique would not require revision so often.

C-Reactive Protein

Inflammatory markers such as C-Reactive Protein (CRP) have the potential to indicate the degree of inflammation caused by the surgery and, thus, the damage to the surrounding soft tissue structures. Kayani et al. measured serum CRP levels in both RATKA and conventional TKA postoperatively at six hours, one day, two days, seven days, and 28 days.[11] They found there to be no significant difference in CRP serum levels at six hours (p=0.717), one day (p=0.1), two days (p=0.473), and 28 days(p=0.361).[11] However, at seven days postoperatively, RATKA had significantly lower CRP levels (p=0.004).[11] Xu et al. had a similar method design to Kayani et al. where they measured serum CRP at one and three days postoperatively.[13] They found that after one day, there was no significant difference ($p=0.141$), but after three days postoperatively, the serum CRP levels were significantly lower in the Mako-assisted TKA study group ($p=0.01$).[13] Another study by Xu et al. found contrasting evidence.[15] This study measured serum CRP levels at one day, three days, and 30 days postoperatively.[15] Their study showed no significant difference in serum CRP levels at any measured time points ($p>0.05$).[15] Serum inflammatory markers can be quantified and are yet another indicator of better patient outcomes the more that they are reduced.

Cost effectiveness

In the current healthcare landscape, alongside evidence-based medicine, cost-analysis and profit margins play a significant role in determining the implementation or denial of procedures, systems, or guidelines. Cool et al. conducted a retrospective claims analysis with the aim of providing longitudinal assessments of a 90-day episode-of-care (EOC) cost analysis, comparing two knee replacement techniques: robotic-assisted total knee arthroplasty (RATKA) and manual total knee arthroplasty (mTKA).[21] Their findings revealed that the overall 90-day EOC costs for RATKA ($18,568) were significantly lower ($p<0.0001$) compared to mTKA ($20,960), indicating an average cost reduction of 11% ($2,391).[21] Even when considering the additional cost of the preoperative CT scan required for RATKA, the savings amounted to over $2,150.[21] Pierce et al. conducted a retrospective longitudinal analysis using a commercial claims dataset to assess the utilization of services within 90 days postoperatively for RATKA and mTKA.[22] Their study indicated that patients who underwent RATKA utilized significantly fewer inpatient services ($p=0.0444$) within the 90-day post-surgery period, with a rate of 2.24% compared to mTKA's rate of 4.37%.[22] Similarly, the use of skilled nursing facilities was significantly lower for RATKA (1.68%) compared to mTKA (6.05%) ($p<0.001$), and the RATKA group exhibited a significantly lower number of home health days (5.33 days) compared to the mTKA group (6.36 days) ($p=0.0037$).[22] Post-surgical costs associated with RATKA were $1,332 less than mTKA ($6,857 vs $8,189, p=0.0018), and the 90-day global expenditures further demonstrated RATKA's cost advantage, with $4,049 less in costs compared to mTKA ($28,204 vs $32,253, p=0.0001).[22] If a particular technique consistently demonstrates greater cost benefits, it may garner favor from those seeking to maximize hospital profits.

Conclusion:

RATKA has demonstrated greater accuracy of implant positioning as evidenced by improvements in the hip-knee-ankle (HKA) angle and a reduction in the number of surgeries that deviate ≥3° from the preoperative plan. Conversely, conventional TKA has been shown to be superior in terms of mean operative time. However, the learning curve of RATKA trends towards potential equivalence of operative time with more experience. The patient outcomes have all shown similar results between the two groups, apart from EBL, LOS, and CRP, and cost which trend toward better outcomes in RATKA. Accordingly, the recommendation is for practicing providers to consider RATKA when a more precise implant position is necessary for a patient at a lower risk for intraoperative complications due to the length of surgery. In contrast, conventional TKA may be indicated if the patient is at a higher risk of intraoperative complications, where decreased surgery time is a critical consideration at the cost of accuracy.

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Appendix A

Author	Year	Study Design	Number of Participants	Key Findings	Comments/ Limitations
Onggo et al.	2020	Multidatabase meta-analysis according to PRISMA guidelines	18 studies totaling 2234 rTKA and 4300 cTKA	Significantly **fewer outliers** in the mechanical axis, femoral coronal, and tibial sagittal angles for rTKA Significantly **longer operative time** for rTKA Significantly **less EBL** in rTKA **Similar rates of complications** and **revision surgeries** between the two study groups	Although a total of 18 studies were reviewed, not every outcome researched was supported with the same number of articles
Held et al.	2022	Multi-surgeon retrospective cohort analysis	111 imageless RA-TKA patients and 110 CM-TKA patients	**Nonsignificant difference** for complications and revision surgeries	Retrospective cohort study is a weaker level of evidence than a RCT
Li et al.	2022	A prospective randomized and multicenter study	73 RATKA and 77 cTKA	**Significant difference** in **HKA angle** alignment for RATKA	Study used a new robot called the HURWA robot
Batailler et al.	2022	Matched comparative cohort study	20 bilateral RATKA matched to 20 bilateral cTKA	Significantly **better HKA angle alignment** from RATKA Significantly **less HKA angle outliers** as a result of RATKA Significantly **longer operative time** for RATKA **Similar** EBL, LOS, and number of complications between study groups	Small sample size Added variable of bilateral TKA
Thiengwittayaporn et al.	2021	Prospective randomized controlled study	75 RATKA and 77 cTKA	Significantly **better HKA angle** alignment for RATKA Significantly **less outliers** in terms of HKA, coronal tibial, sagittal tibial, and sagittal femoral angles for RATKA Significantly **longer operative time** in the first 10 RATKA cases **Similar operative time** between the last 10 RATKA and cTKA groups	Additional finding was a learning curve determined to be seven cases
Kayani et al.	2021	Prospective randomized controlled trial	15 cTKA and 15 RATKA patients	Significantly **greater HKA angle alignment** for RATKA **No significant difference** found for	Small sample size

				operative time nor postoperative complications Significant difference in serum CRP levels found only at **7 days postoperatively**	
Vaidya et al.	2020	Prospective randomized controlled study	32 R-TKA and 28 C-TKA patients	Significantly **greater HKA angle** alignment for RATKA	Small sample size
Xu et al.	2022	Retrospective cohort analysis	34 MA-TKA and 31 CM-TKA patients	Significantly **greater HKA angle alignment** from MA-TKA Significantly **less EBL** resulted from MA-TKA **Significantly lower serum CRP levels** in the MA-TKA group at **72 hours postoperatively**	MAKO Robot Small sample size Study was conducted on Chinese patients
Choi et al.	2022	Retrospective cohort analysis of a prospectively collected database	60 RFA-TKA and 60 MA-TKA patients	Significantly **higher amount of outliers** in the femoral coronal and tibial sagittal angles **No significant difference in outliers** of the mechanical axis, femoral sagittal, or tibial coronal angles **No significant difference** in HKA angle alignment	Additional variable studied of functional alignment in the robotic group vs mechanical alignment in the manual group
Xu et al.	2022	Prospective random controlled study	37 RA-TKA and 35 CM-TKA patients	Significantly **longer operative time** for RA-TKA **No significant difference** found for HKA angle alignment, EBL, LOS, or amount of postoperative DVTs **No significant difference** found for serum CRP levels	Small sample size DVTs were measured at 30 days postoperatively
He et al.	2022	Retrospective cohort analysis	30 COTKA and 30 RATKA patients	Significantly **less EBL and LOS** in the RATKA group **No significant difference** found in HKA angle alignment, operative time, complications, or revision surgeries	New robot was used called “SkyWalker” Small sample size Retrospective cohort analysis is weaker evidence than a RCT
Smith et al.	2021	Prospective Cohort Analysis	120 consecutive RA-TKA and 103 consecutive manual TKA patients	Significantly **increased operative time** for RA-TKA Significantly **less LOS** from RA-TKA **No significant difference** found for complications and revision	Cohort study is not as strong evidence as a RCT

				surgeries	
Marchand et al.	2022	Retrospective cohort analysis	140 RATKA and 60 manual TKA	**No significant difference** was found between the manual and six-month RATKA groups regarding operative time RATKA at one year was statistically significantly **faster** than manual TKA	All surgeries were performed by the same surgeon Study groups for RATKA were stratified by experience at one, six and 12 months
Sodhi et al.	2018	Prospective cohort analysis	240 RATKA cases between two surgeons	Both surgeons found a significantly **longer operative time** in their first 20 cases of RATKA Both surgeons' last 20 RATKA cases had **no significant difference in operative time** to manual TKA	Mako System was used Both surgeons were new to RATKA One surgeon completed 180 of the cases and one completed 60
Fontalis et al.	2022	Prospective randomized controlled trial	15 RATKA and 15 conventional TKA	**No significant difference** was found for LOS between the two study groups	Small Sample size
Cool et al.	2019	Retrospective longitudinal analysis	519 RATKA and 2595 mTKA	**RATKA had significantly less** 90-day EOC costs	Data obtained from Medicare 100% Standard Analytic Files
Pierce et al.	2020	Retrospective longitudinal analysis	357 RATKA and 1785 MTKA	**RATKA had significantly less** inpatient service, skilled nursing facility, and home health utilization, **RATKA had significantly less** overall post-surgery costs and global expenditures	Database was only from 2016 to 2017

Table 1. Summary of evidence