

# Advances in Computer-Assisted Robotic Knee Replacement Surgical Methods

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**Abstract:** TKA (total knee arthroplasty) is one of the most prevalent operations among the treatments for patients who suffer from OA (osteoarthritis) of the knee. The postoperative patient satisfaction rates for TKA remain lower than expected despite the procedure being one of the most successful in orthopedics with excellent survivorship. In recent years, the development of technology in surgical techniques has caused robotic-assisted methods to become more popular. Surgical robots have increased the number of robotic-assisted TKA operations due to fewer postoperative pains, quicker recovery times, and shorter hospital stays. According to this theory, the amount of bone resection and soft tissue damage, both significant pain sources, will be minimized with this technology. Through the use of robotic assisted systems, surgeons can achieve consistent surgical outcomes using a minimally invasive operating environment that eliminates the uncertainty associated with knee arthroplasty. Our study aimed to investigate the importance of this method of surgery, advances new techniques, the clinical outcomes and postoperative results, and the management of the operation. Restrictions of RATKA (Robotic Assisted Total Knee Arthroplasty) include high installation costs and learning techniques for gaining surgical skills, and compatibility of the robotic technology with a limited number of implant designs.

**Keywords:** Robotic Surgery, Total Knee Arthroplasty (TKA), Robotic-Assisted Total Knee Arthroplasty (RATKA)

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## 1. Introduction

The development of surgical care over the past 3 decades has led to a sudden increase in both patients' life expectancy and quality of life. New surgical techniques, like laparoscopic, robotic, minimally invasive, laser, and other innovative techniques, are applied mainly according to their purpose and their impact [1]. In surgical procedures, the deployment of new technologies raises many ethical changes, including how to determine safety, when to deploy new technologies, how to inform patients before undergoing new procedures, and how to evaluate them [2]. A surgeon can get a full visual and tactile understanding of the surgery during open surgery. Nevertheless, patients are likely to experience significant trauma and invasiveness as a result of this type of surgery. As a result of minimally invasive surgical (MIS) techniques, there are fewer incisions or no incisions at all, resulting in a short recovery period and a reduced level of pain after surgery [3]. Innovative surgical procedures are defined as "new or modified surgical procedures that differ

from locally accepted practices and whose outcomes have not been described and may be associated with patient risks" [4]. Due to advances in surgical technology, surgeons were able to utilize this approach to its full potential. The minimally invasive surgical approach has revolutionized surgical care, reducing postoperative pain and recovery time as well as hospital stays, improving cosmetic results, and reducing costs. [5]. To perform a highly accurate diagnosis, surgical reconstructive methods are constantly improving, as well as prosthetic demands are increasing. A new generation of implant placement methods has been developed to address these requirements, which have led to the increased use of advanced radiographic methods [6]. As a result of changes in the workforce and economic conditions, surgical education is changing. In the operating room, simulations and other technical methods are used to teach skills that transfer to the operating room. It is difficult to acquire and maintain competence in the management of traumatic injuries due to a decline in the operations of traumatic injuries [7]. There is a continuous development of surgical concepts and techniques,

and surgeons must keep up with these changes. With technological advancements in the past two decades came new advancements that could significantly transform our teaching methods through new multimedia technologies [8]. Total Knee arthroplasty (TKA) is one of the most successful treatments for osteoarthritis of the tricompartmental knee. With the development of computer navigation and robotic-assisted surgery (RAS), it is now possible to plan and execute surgery with greater precision and consistency, ultimately improving the success rate for TKA patients [9]. Orthopedic surgeons are increasingly interested in surgical variables controlled intra operatively, including lower leg alignment, component positioning, and soft tissue balance. The use of computer navigation and robotic-assisted systems has been developed in conjunction with unicompartmental knee arthroplasty and total knee arthroplasty (TKA) since tight control over these factors has been linked to improved outcomes [10]. In recent years, computer-assisted surgery and robot-assisted surgery have been introduced to improve implant positioning [11]. Based on the New York Statewide Planning and Research Cooperative System database, between 2008 and 2015, yearly increases were observed in total knee replacements performed with technology. Although both studies relied on databases that incorporated biased samplings of national practice trends, they weren't without their limitations [12]. Since the late 1980s, robots have been used in surgery. Robotic technology was introduced into orthopedic surgery in 1992 with ROBODOC, an instrument that planned hip and knee replacements using robotics [13]. Efforts are currently being made by both technology developers and surgeons to overcome specific limitations of conventional jig-based alignment techniques in order to increase the precision and accuracy of resections, robotic-assisted knee arthroplasty is becoming increasingly commercially available [14]. The use of computer-assisted or computer navigation surgery systems, also known as passive surgery systems, enables surgeons to monitor progress and gather data during surgical procedures [15]. Increasing interest in robotic-assisted surgery can be attributed to the technical challenges involved in performing UKA through a minimally invasive approach [16]. In addition to the high installation costs and radiation exposure, robotic TKA is limited in the number of implant designs that can be used. In addition, it is also limited in the learning curve required for gaining surgical proficiency [17]. Numerous studies have demonstrated that nearly 20% of total knee arthroplasty patients are dissatisfied with their overall outcomes despite improvements in implant design, surgical technique, and postoperative rehabilitation [18]. The use of robotic technology could theoretically enhance this accuracy due to the combination of navigation and mechanical precision. However, the excessive operating time required for the robotic implantation, the technical complexity of the system, and the extremely high operational costs have led us to abandon this procedure [19]. Using this technique for bone resection may result in inadvertent injury to ligamentous structures, compromising postoperative clinical and

functional recovery, reducing stability, and reducing implant survival rates [20, 17].

## 2. Advances in Surgical Techniques

In the context of advanced surgical techniques, the issue of surgeon skill levels comes into play when determining whether innovation should be organized as research or as surgical practice [2]. As a result of this ancient tradition, the field of experimental medicine began to explore unproven concepts of therapy in the early twentieth century, assuming that the body's response to illness or trauma was a natural physiological reaction rather than a pathologic reaction resulting from any condition or pathology. Among the most important advancements in this direction has been the introduction of new surgical techniques in order to ensure quality control and patient safety [21].

### 2.1. Minimal Invasive Approaches

Modern surgical practices have been completely revolutionized with this new approach, changing surgical ways of thinking, surgical techniques, and all other aspects of modern surgical care. With MIS, patients are relieved from postoperative pain, recover quickly from surgery, and have a shorter hospital stay. They also have better cosmetic outcomes and lower overall costs. By reducing morbidity and maintaining the quality of care, minimal access to surgery has changed the way surgery is performed [21, 22]. A minimally invasive approach consists of making a smaller skin incision, avoiding extra eversion, and utilizing effective techniques to achieve the desired result [23].

### 2.2. Surgical Options

There are traditional open surgery, laparoscopic surgery, and robotic-assisted surgery which are common options. It has already been reported how open and laparoscopic surgeries are performed. Laparoscopic and open procedures were conducted according to the same standardized principles and steps [24]. There are various types of new surgical options, such as laparoscopic, robotics, minimally invasive, laser, and other non-conventional procedures that are applied according to their purpose and impact on the patient and the use of such techniques would contribute to further discussion about how to strike a balance between innovation and regulation [1, 2]. A range of surgical options is available for treating knee osteoarthritis, including arthroscopy, osteotomy, and total knee replacement, depending on several factors, including the location and severity of the damaged joint, patient characteristics, and the risk factors associated with it [25].

### 2.3. Surgical Timing

Due to the focus on decreasing variability and increasing precision, operations have become longer as a result of the greater precision and decreased variability [26, 27]. Periprosthetic joint infections are known to be associated with

increased operative time, regardless of the percentage of aborted procedures. Considering the potential for patient harm, robotic-assisted procedures remain detrimental [27, 28].

### 3. Total Knee Replacement

Both the incision and the exposure to the knee joint need to be planned correctly prior to total knee replacement surgery. There is no doubt that these factors are just as important to achieving the best outcome as the choice of the right implant, positioning the components, and balancing the ligaments [29]. The replacement of individual joints is possible, such as a patellofemoral joint replacement, a unicompartmental knee arthroplasty (UKA), or a total knee arthroplasty (TKA) [30]. Osteoarthritis (OA) of the knee that is beyond treatment is best treated with a total knee replacement. Knee replacement surgery, also known as total knee arthroplasty, is a safe and cost-effective treatment for severe OA of the knee joint [25, 31].

#### 3.1. Total Knee Replacement Methods

A total of two joints (medial and lateral femorotibial) along with the patellofemoral joint are replaced during surgery [32]. There are three main approaches for a primary TKA procedure: medial parapatellar, midvastus, and subvastus methods [33, 34]. (Table 1) For knee replacement to be successful, it is essential to achieve a balanced fissure and extension gap, maintain adequate and equal soft-tissue tension medially and laterally, maintain the joint line, achieve limb alignment, and place the implant properly that helps achieve near normal knee kinematics. [35, 36]. An orthopedic surgeon performs a total knee arthroplasty using hand-held power tools, intramedullary canal rods, extra medullary jigs, mechanical blocks, and other mechanical instruments [37, 38]. In the last few decades, many methods for achieving accuracy in total knee replacement have been devised using improvements in instrumentation, navigation, and robotic techniques. With the advancement of robotic technology, joint replacements are becoming increasingly common [35, 39].

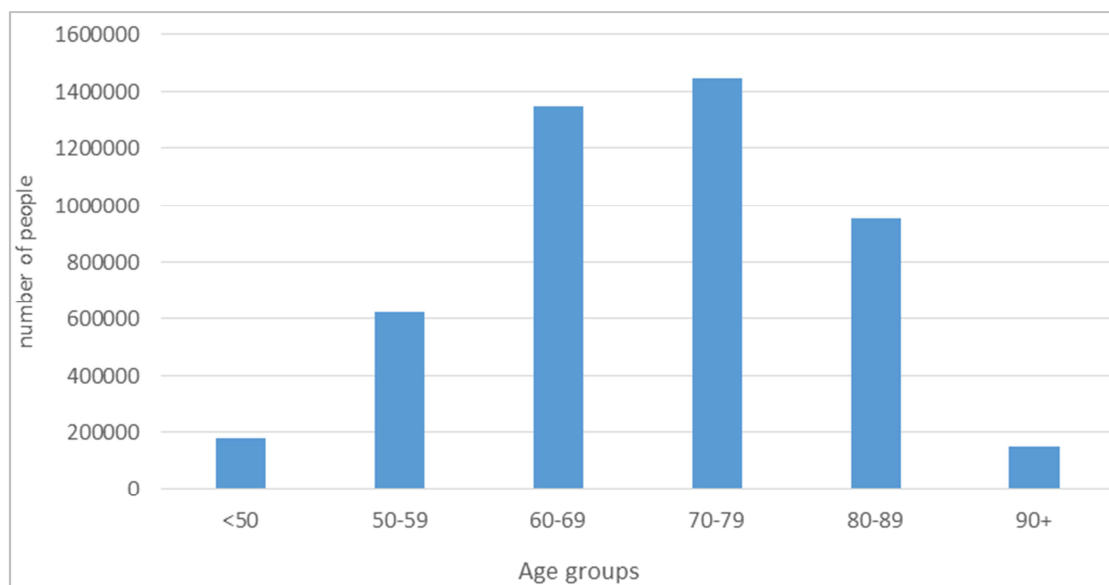
*Table 1. Three main approaches for a primary TKA procedure [34].*

Approaches for a primary TKA	dissections	protections
Medial parapatellar	proximal dissection through a medial cuff of the quadriceps tendon, distal dissection medial subperiosteal	proximal tibial bone
midvastus	vastus medialis oblique	the quadriceps tendon
subvastus	vastus medialis oblique	the quadriceps tendon

#### 3.2. Total Knee Replacement Indications

Osteoarthritis accounts for 94-97% of TKR operations, with most being performed as a result. There is a complex interaction between constitutional and mechanical factors that determine a person's risk of knee osteoarthritis [40]. These procedures are mainly performed for the treatment of osteoarthritis (OA) [41, 42]. As well as inflammatory arthritis, fractures (because of post-traumatic osteoarthritis and/or

deformities), dysplasia, and malignancy, others [34]. The prevalence of OA is increasing due to the aging population and the obesity epidemic. In consequence, there is likely to be an increase in TKA procedures [41, 43]. Artificial knee joints are currently prevalent in the United States, but the prevalence is unknown. As a result of improving life expectancy, joint replacement has become more common in younger individuals, creating a large pool of individuals with knee replacements in the United States. (figure 1) [44-46].



*Figure 1. According to age group, the number of individuals who underwent a total knee replacement in the U.S. in 2010.*

Robotic total knee arthroplasty

### 3.3. Robotic Technology

Manufacturing has utilized robotics for decades, but medical applications of the technology have only recently emerged [47]. Therapy can be made more efficient and accessible through the use of robotic technology that assists therapists in providing consistent training over a prolonged period, as well as collecting data about progress [48]. General surgery has been trending toward less invasive treatments, such as laparoscopic surgery and robotics [49]. It is possible to perform robotic surgery in different ways using different robot types. It has been determined that these robotic approaches fall into three categories: passive, semi-active, and active approaches [50-52]. During passive systems, a portion of the procedure is completed under the direct and continuous supervision of the surgeon. It is not necessary to involve a surgeon in the operation of active systems. Compared to fully active systems, semi-active systems provide surgeons with feedback to enhance their control and, theoretically, their safety [52]. (Table 2).

**Table 2.** Contemporary Robotic Platforms for TKA [52, 53].

Names	Applications	Robotic types
ROBODOC	TKA, THA (Femur)	active autonomous
MAKO	TKA, UKA, THA	Semi-active
IBLOCK	TKA (Femur)	active autonomous

TKA - Total Knee Arthroplasty, UKA - Unicompartmental Knee Arthroplasty, THA - Total Hip Arthroplasty.

### 3.4. Total Knee Arthroplasty

Osteoarthritis of the knee is treated with total knee arthroplasty (TKA), an established and highly effective procedure. [17, 54, 55]. Total knee arthroplasty (TKA) has only recently incorporated robotic technology, unlike other surgical specialties [56]. An advantage of robotic-assisted total knee arthroplasty (RATKA) is the more precise positioning of implants and better quantification of soft tissue balance, which might lead to improved functional outcomes and satisfaction for patients [57-59]. The development of advanced technologies for improving cut accuracy has included computer-assisted infrared tracking or "navigated" total knee arthroplasty (TKA) as well as patient-specific instrumentation and cutting guides [38, 60].

### 3.5. Outcomes of Robotic TKA

As compared to traditional knee replacements, robotic-assisted knee reconstructions may provide significant alignment advantages. However, most meta-analyses of alignment outcomes focus on patients with computer-guided knee arthroplasty and patient-specific instruments [61]. In addition to its potential benefits to both patients and surgeons, robotic-arm-assisted TKA technology offers various advantages as well. The RATKA procedure can help

surgeons and their surgical teams to perform surgical procedures more accurately, protect soft tissues better, improve patient satisfaction, shorten the learning curve, make the surgery more ergonomic, and reduce fatigue for surgeons and surgical teams. It is possible that the above advantages may help improve clinical outcomes, surgical outcomes, and patient-reported outcomes [58].

## 4. Operation Management

### Operative Preparation and Measurements

During manual surgery, bones are prepared by the medial parapatellar technique with the little medial release. The standard TKA (Stryker) instrument is used to perform manual preparation of triathlon cruciate holders. A level on the femur is measured intramedullary, whereas a level on the tibia is measured externally. The insertion of a femoral intramedullary rod can be performed using a fluoroscopy machine [62].

### 4.1. Preoperative Management

Image-guided robotic TKA requires specialized preoperative preparation including a CT scan, which can increase radiation exposure and time. A robotic products specialist is needed in the operating room to capture data from the patient-specific virtual models used for remote preoperative planning and segmentation. In addition, some studies have found that fully active robotic TKA systems can cause soft-tissue injuries around the joints, and technical issues have led to the conversion of fully active robotic TKA to conventional jig-based TKA during operation [63-65]. After the fiducial clusters were correctly fixed on each leg, we performed preoperative CT scans on all knees [62]. In addition to preoperative analysis, intraoperative sensors, and robotically controlled instruments, these are areas of critical importance. To determine the boundaries and operative plan of robotic surgery, some type of imaging modalities, such as CT or radiographs, is used for preoperative planning with current robotic technology [27].

### 4.2. Postoperative Management

The CT scans were conducted on a single scanner using a standard protocol three months following surgery. DICOM (Digital Imaging and Communication in Medicine) format was used to save postoperative CT scans [66, 67]. After the surgery, postoperative CT was used to determine the accuracy of component positioning by comparing preoperative target positioning values with postoperative values [66, 68]. The patient can begin walking and range of motion exercises two to four hours after surgery. The surgical procedure involves the administration of one unit of autologous blood [69-71].

### 4.3. Clinical Management

The standard arthroplasty regimen uses sodium warfarin

with a low dose regimen to prevent deep venous thrombosis. In most cases, patients are discharged to rehabilitation centers on the second day after their surgery. Depending on the patient's condition, some may be able to go home directly after the procedure. For those that may have to go home directly, an anticoagulant pent saccharide may prove effective (fondaparinux, Arixtra) in preventing clot formation [69-71]. The ERAS (enhanced recovery after surgery) procedure has recently been developed for patients who have undergone TKA. It improves clinical outcomes, reduces hospital admission costs, and reduces the time before the first out-of-bed activity [72, 73].

## 5. Discussion

### 5.1. The Complexity of Robotic Systems

The surgeon analyses the cuts suggested by the robotic system during this step. The surgeon was likely most efficient at this step due to his ability to rely on the intraoperative plan the more he used the robot. Depending on the degree of deformity at the time of surgery or the complexity of the robotic surgical system, this discrepancy could be explained. The use of robotics in the OR should lead to enhanced workflow efficiency, patient satisfaction, and patient safety in future generations. Robotics in the operating room is not only expensive but also requires a lot of education for surgeons and staff in order to be safe and useful. Future designs should include comprehensive training to resolve robotic complications to prevent such unplanned injuries.

### 5.2. High Expenses

Although robotic technology is being used in the treatment of TKA more and more, the cost of the procedure is growing in conjunction with the popularity of these procedures. There are serious concerns among healthcare payers regarding the rapid growth in robotic TKA, which cost far more than the considered budget. We hope researchers attempt to trace this matter as soon as possible.

### 5.3. Sub-acute Post-Operative Pain

Despite significant progress in TKA over the last five to ten years, challenges remain for coming development. An enhanced understanding of specific preoperative risk factors may allow such patients with maybe a few more days of hospitalization and active monitoring. It is imperative to optimize analgesia, especially afterward discharge, because there is a significant risk of sub-acute pain in the first few weeks following TKA, which may affect activities, recovery efforts, and even long-term function. Analgesic treatment should be defined in terms of configuration, drugs, and period. Another pain issue concerns the development of preoperative techniques for identifying patients with high pain risks. It is necessary to focus more on medical morbidity in the future, since there will be different approaches to improving this statistic. Finally, In addition to the topics

mentioned above, future research should focus on revision TKA, which may present more complex problems with surgical technique, pain, and morbidity.

## 6. Conclusion

With the development of new surgical techniques especially in robotic knee surgery, patients should be provided with the best possible medical care in the health system. In light of the fact that this technology is relatively new, further research is needed to correlate clinical outcomes with patient satisfaction. There is a continuous introduction of new surgical technologies, and it is imperative that these modalities be evaluated, particularly in terms of improving patient satisfaction. Therefore, future researchers should further develop robotic-assisted TKA by solving the mentioned problems.

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