

# THE FUTURE OF ROBOTIC TKA SURGERY - A CRITICAL REVIEW BUT POSITIVE OUTLOOK

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## SUMMARY

**Background:** Total knee arthroplasty (TKA) is a rapidly expanding sub-segment of orthopedic surgery. While computer-assisted surgery (CAS) and robotic-assisted surgery (RAS) have been developed to enhance surgical precision and reproducibility, the definitive clinical superiority of these technologies remains a subject of significant debate within the orthopedic community.

**Objective:** This review evaluates the current state and future trajectories of robotic-assisted systems in knee arthroplasty, addressing existing technological limitations, cost-effectiveness, and the transition toward data-driven surgical planning.

**Key Points:** Robotic platforms demonstrate superior accuracy in bone preparation, component positioning, and ligament balancing compared to conventional manual instrumentation, particularly for less experienced surgeons. However, widespread adoption is hindered by high capital costs, bulky hardware, and potential pin-site complications. Current research indicates that while CAS technologies have reached a maturity plateau, RAS publications continue to increase. The future of the field involves integrating augmented reality to eliminate line-of-sight issues and utilizing collaborative intelligence. This "closed-loop" approach aims to transition RAS from a tool for precise execution to a predictive system that utilizes large-scale perioperative data and machine learning to determine patient-specific alignment targets and optimize functional outcomes.

**Conclusion:** Although RAS provides highly reproducible mechanical execution, its long-term clinical value depends on defining optimal personalized alignment goals. Surgeons must focus on integrating multi-dimensional data to justify the cost-efficiency of these technologies through improved patient-reported outcome measures and reduced revision rates.

## KEYWORDS

Arthroplasty, Replacement, Knee; Robotic Surgical Procedures; Surgery, Computer-Assisted; Treatment Outcome; Artificial Intelligence

## INTRODUCTION

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Orthopedic surgery is one of the most dynamic surgical specialties, and knee arthroplasty surgery is one of its fastest-growing sub-segments. In parallel of this growth, computer assisted surgery (CAS) using computer navigation, patient specific instrumentation and sensors have been progressively developed to increase the accuracy and the reproducibility of total knee arthroplasty (TKA). The latest CAS technology gaining interest is robotically assisted surgery (RAS) in knee arthroplasty. Despite the high accuracy and the reproducibility during TKA procedures brought by the robotic system, clear clinical advantages and superiority of these innovations have not yet been proven. The place of RAS in orthopedic surgery in the future, particularly in knee arthroplasty, is not yet well defined and remains subject of debate. Several questions about the ultimate goal of RAS are not settled now. In this article we will give a critical review but aimed to give some positive outlooks about the future of RAS in knee arthroplasty.

## VISIONS OF FUTURE RAS FOR KNEE ARTHROPLASTY

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Three different visions of the future of RAS for knee arthroplasty exist currently, which will be described in more detail.

The super optimistic vision could be described as the “cyborg of the TKA league” (Figure 1).

### The super optimistic vision



Figure 1: The super optimistic vision of future of robotic TKA.

This vision, wished by the kids, integrates the robots in surgery like it can today be seen in the movies. The surgeon could do the planning with his hands on a 3-D hologram model such as in Minority Report. Concerning the cutting tools that we are using daily; we all have wished to have a “magic laser” cutting only the bone but not the soft tissues. The first orthopedic contact free bone cutting laser has been CE approved in February 2021

(CARLO which stands for Cold Ablation Robot-guided Laser Osteotome, AOT startup, Basel Switzerland). So far, there is nothing ready yet for TKA, let alone a laser coming from an extension of the Surgeon's glove.

The pessimistic vision on the other hand is probably too negative (Figure 2). Most of the opponents of RAS in orthopaedics are claiming that these solutions are just trends coming one after another from the industry that will fade. Several surgeons state that RAS is a fashion and a marketing ruse only [1, 2].

## The pessimistic vision ?

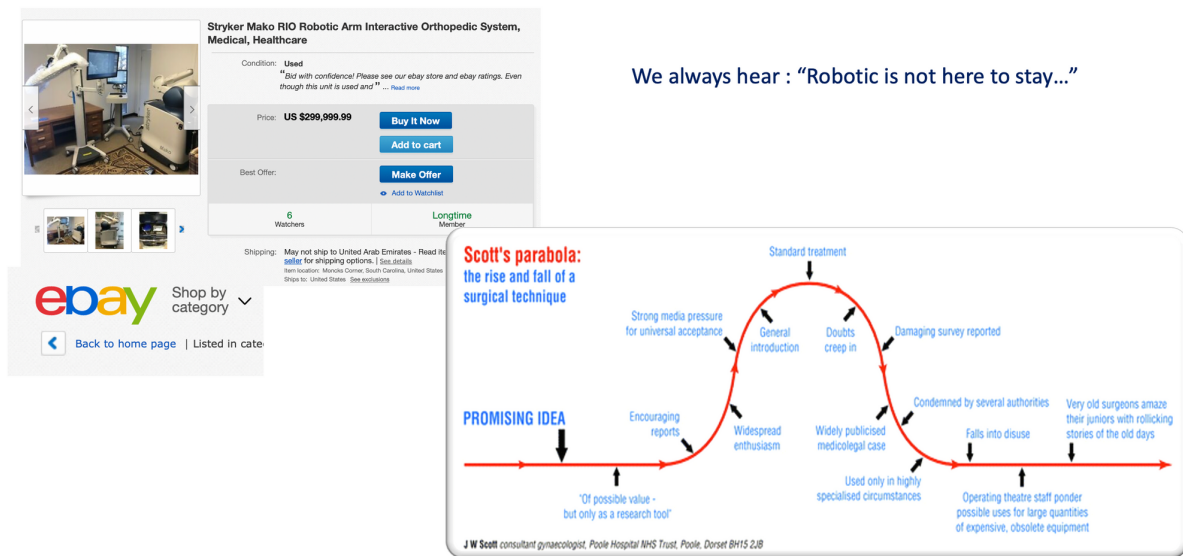


Figure 2: The pessimistic vision of future of robotic TKA

They often use the Scott Parabola as a reference to describe the rise and the fall of these new surgical techniques [3]. This parabola represents a procedure or therapy that shows great promise at the outset, becoming the standard treatment after reports of encouraging results, only to fall into disuse due to adverse outcome reports. RAS would know the same fate, and robotic platforms would be auctioned off in the near future.

The most realistic vision lies behind these two scenarios where RAS will stay and continuously evolve. In fact, in a recent analysis of the literature for CAS use in knee arthroplasty including 4,085 articles (MS in press) the orthopaedic techniques assessed in this study were not following the "Scott's parabola" (Figure 3).

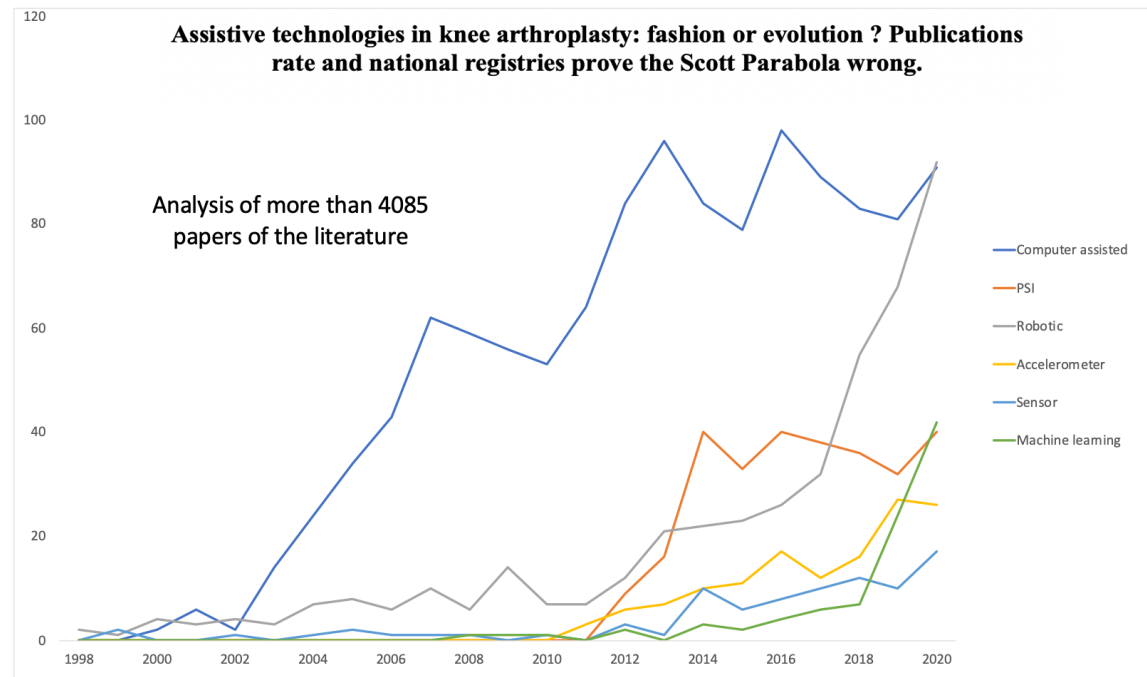


Figure 3: The evolution of assistive technologies in knee arthroplasty in the literature.

Computer navigation and patient specific instrumentation for TKA have increased quickly, then reached a plateau, with a stable number of publications over the last six years. This “consolidation phase” can be interpreted as a form of maturity of the technique. The number of publications concerning RAS, accelerometers and sensors continues to rise. RAS probably will follow the same evolution and reach a plateau in the future. Even if the clear advantages and superiority of these assistive technologies are not yet entirely demonstrated, new paradigms concerning alignment are reaffirming the need for these assistive technologies . Each technique contributes partially to a better understanding of what we are doing and how to achieve it to improve functional results and patient satisfaction after knee arthroplasty.

## BENEFITS OF ROBOTIC

The main benefit offered by robotics is accurate and reproducible bone preparation due to a robotic interface, whatever system is used [4-6]. The aim of robotic systems is not to replace the surgeon but to improve their performance. The accuracy for TKA with RAS is higher than using standard instrumentation performed by experienced surgeons and especially compared to less experienced surgeons (Figure 4).

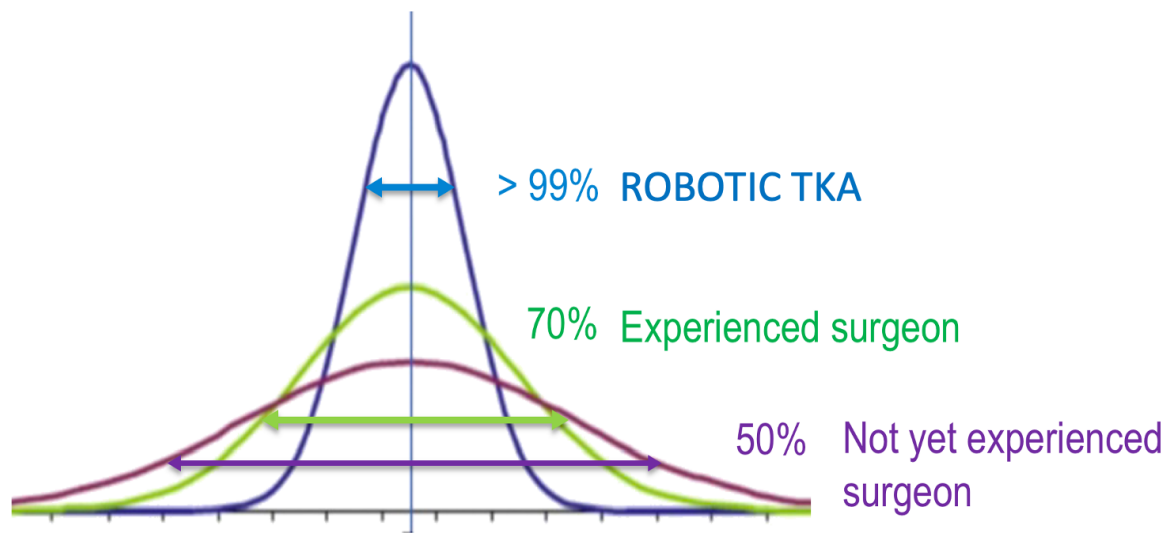


Figure 4: The accuracy of the robotic TKA compared to standard TKA performed by experience or less experienced surgeons

These systems improve the accuracy of femoral coronal and sagittal alignment, tibial coronal and sagittal alignment, joint line restoration, tibial slope, and limb alignment, compared to a conventional technique [7]. They allow a significant reduction of the outliers and thus a reduction of the failures after knee arthroplasty. This reduction of revision due to a lower rate of outliers has been demonstrated mainly in unicompartmental knee arthroplasty so far [5, 8]. Implant's sizing is also improved by the use of a robotic system. The control and the improvement of ligament balancing can be easier with a robotic system than with a conventional technique. These systems register the ligament balance or imbalance before the intervention, the planned ligament balancing, and the balance at the end of the procedure. During all of the surgery steps, the surgeon can assess the ligament balancing and make adjustments. However, the clinical benefits of RAS remain yet uncertain. This absence of significant difference is also probably related to the fact that initially, the mechanical alignment target was used for every patient. Now, with more personalized targets of alignment and ligament balances, significant differences might be observed.

## A NEED FOR HARDWARE AND SOFTWARE IMPROVEMENTS ---

Robotic platforms are very attractive however today, several points limit a broader adoption, including costs and some limitations related to the hardware and/or the software. The cost of these devices remains very high and inconceivable for most surgeons. Indeed, the costs associated with purchasing and operating robotic systems include the robot tool itself and operational costs, additional robot set-up time and technician in the OR, the disposables and the preoperative imaging and scans (with some robotic systems). As with all medical technologies, these expenses vary widely between each robotic system based on the unique manufacturer's license agreements, hospital volume, and negotiated pricing. The price of the various robotic systems is reported to be between \$400,000 and \$1.2 million. Disposable costs vary slightly between robotic systems and types of procedures but are estimated to cost between \$750 and \$1300 per case. Alternative payment models may be offered, whereby systems are leased with a per-case pricing model, or there may be no charge to use or maintain the robot, or the implants price may be negotiated, etc. Nevertheless, less than 1% of the surgeons in the world have access to RAS for knee arthroplasty.

The specific hardware required for the use of the robotic system remains unpractical. From the beginning of computer navigation surgery in early 2000 until now, the trackers and the screening system are always similar without significant improvement (Figure 5).

## Hardware from 2001 to 2021

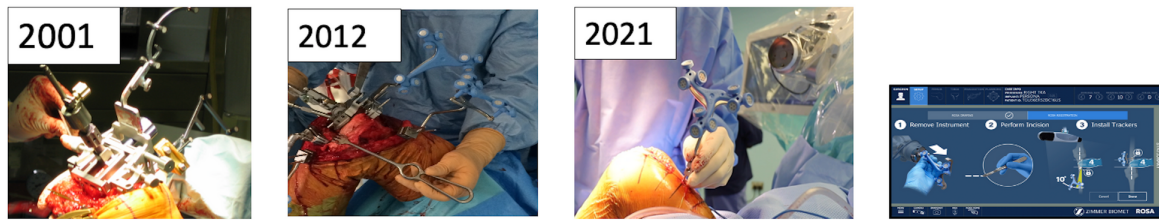


Figure 5: The evolution of the specific hardware of the robotic system in the last 20 years.

The rigid bodies and the trackers are always necessary, associated with an infra-red camera. These tracking pins can occur some complications such as fractures, infections, etc. [9, 10]. The robotic unit and the optical unit are bulky, with several manipulations to position them. Then the registration of bony landmarks, mechanical axis, and knee frontal laxity follows similar steps than computer navigation developed 20 years ago. The advances in these technologies are quite delayed compared to those in our daily life. Our mobile phones have the capacity to recognize a face automatically and to use it in different applications. Why is it not possible with the bones during surgery yet? The screens and connectivity didn't also evolve recently. The surgeons have to look and control the information on the screens next to the surgical field, disrupting the surgical procedure. Mixed reality applications might offer in a near future a better experience, the surgeon being able to have the information displayed directly into his MR glasses. Modern robotic platforms will probably continue to evolve, integrating augmented reality to be able to visualize 3-D and to use intra-operatively 3-D planning without having to look at a screen while operating (Figure 6).

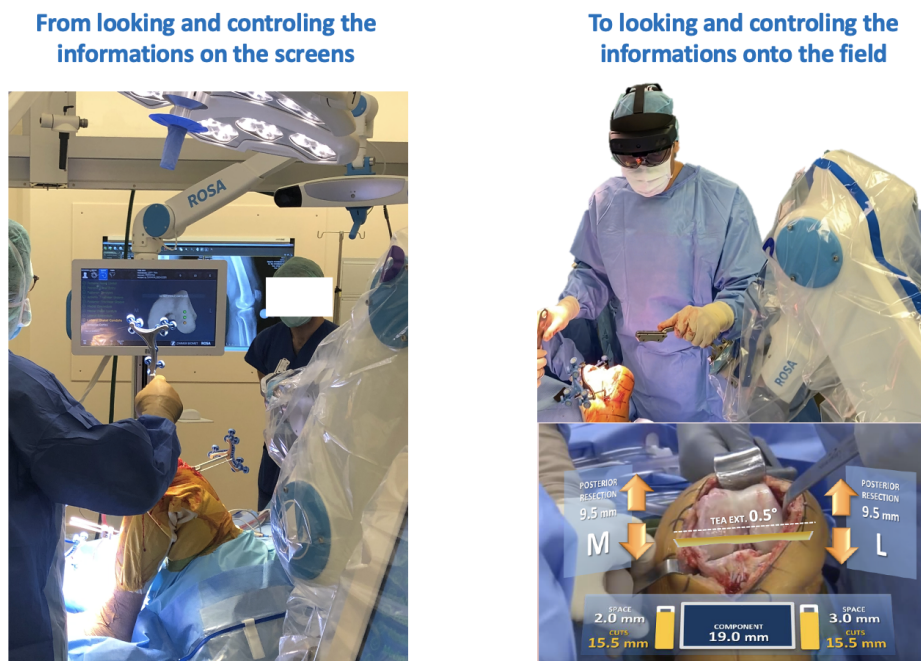


Figure 6: Actual screens and connectivity versus augmented reality in robotic TKA.

# PREDICTIVE ROBOTIC AND COLLABORATIVE INTELLIGENCE

The main question always remains: “How to make sure that our patients will feel better?”. We still don’t know what the ideal goal is in knee arthroplasties. The true challenge in arthroplasties is to improve the software to obtain a goal, then a plan. “A goal without a plan is just a wish.” But in total knee arthroplasty, this expression should be modified: “I wish I could have a goal to make my plan.” Intra-operatively, there are over a million different combinations and there is no evidence what we should aim for TKA planning, alignment targets, 3-D positioning of components and soft tissue balancing. During surgery, most software gives too much information for the human brain to integrate and use appropriately (Figure 7).

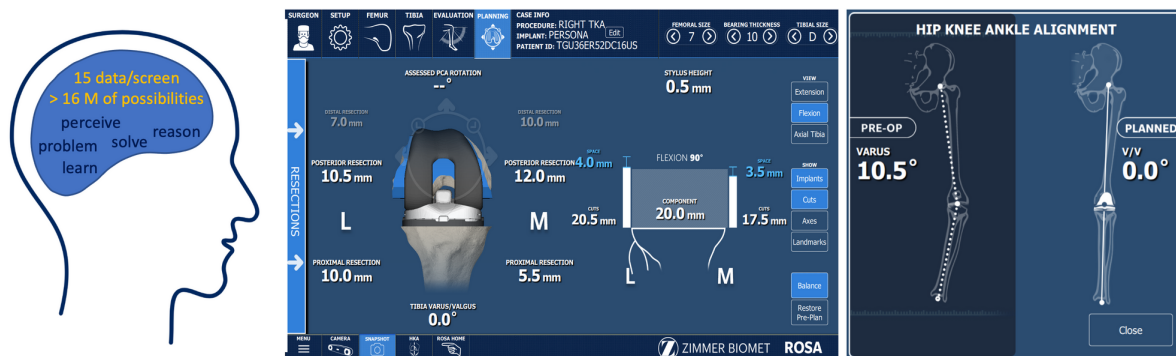


Figure 7: During surgery, too much information for the human brain to integrate and use appropriately.

We have to start an endless four steps process to improve the TKA procedure and reach the ultimate goal which would be to know exactly what to do for which patient (Figure 8).

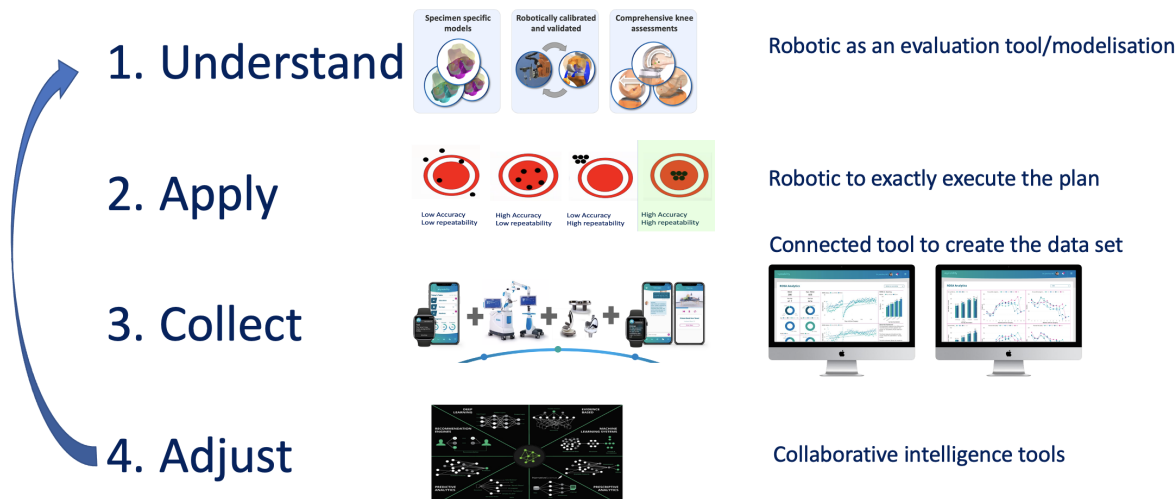


Figure 8: An endless four steps process to improve the TKA procedure and reach the goal.

First, we need to understand what we do during the TKA procedure, using biomechanical and cadaveric studies. The robotic system will allow to create a dynamic model to facilitate this understanding. Secondly, we must be able to apply this plan during the TKA procedure, and the robotic system will allow us to execute precisely the planning with high accuracy and repeatability. Third, all data (preoperatively, intraoperatively, and during all follow-up) should be collected via connected tools to create mega data information’s. Fourth, this mega data should be analyzed using collaborative intelligence tools to adjust the planning with predictive models based on previous experience.

Currently our main missing feature is not knowing the target: "where should we go?". This four steps process is the way to move in the future from a robot telling us where we are to a robot is telling us where we should go and help us achieve it. Understanding how other groups of variables (other than the surgical quality), such as patient-specific characteristics, knee deformities, perioperative settings influence clinical outcomes, becomes increasingly important. Conceivably, using relevant data points incorporated into an algorithm (preoperative clinical and surgical data), the surgeon could improve his practice with this predictive model and incorporate this machine learning tool in the robotic system. That's why some collaborative intelligence platforms connect the pre-, intra-, and post-operative data and allows analyzing surgical decisions with quantifiable data provided by the robotic system. The concept is to "close the loop": learn from every surgery to make the next one better. The analysis of surgical data combined with clinical outcomes could improve our knowledge and the TKA procedure progressively. This improvement of the TKA procedure could help to extend the access of the robotic systems to all the surgeons because the value of RAS in knee arthroplasties could be more conceivable. We as surgeons have the responsibility to work together to provide better cost-efficient processes. This is the principle of value-based health-care measured as the ratio outcome / cost of the episode of care. We as surgeons are still struggling to collect and provide proper measurements of outcomes that matter to patients. We should improve the assessment of patients' outcomes and quality of life to then be able to measure our cost-efficiency.

## CONCLUSION

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Robotics and other CAS technologies are here to stay and to evolve continuously. Engineers can keep on working on the hardware to improve its ease of use and efficiency. But it's the surgeons' responsibility to work on the targets in TKA, to understand better what we are doing and make it valuable for the patients. Finally the supporters will have to prove the benefit of RAS for our patients and the health care system to justify the future investments in these new technologies.

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