



REVIEW ARTICLE

[Translated article] Current situation of robotics in knee prosthetic surgery: A technology that has come to stay?

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Abstract Robotic surgery is a surgical technique that is on the rise. The goal of robotic-assisted total knee arthroplasty (RA-TKA) is to provide the surgeon with a tool to accurately execute bone cuts according to previous surgical planning to restore knee kinematics and balance of soft tissue, being able to precisely apply the type of alignment that we choose. In addition, RA-TKA is a very useful tool for training.

Within the limitations, there is the learning curve, the need for specific equipment, the high cost of the devices, the increase in radiation in some systems and that each robot is linked to a specific type of implant.

Current studies show, with RA-TKA, variations in the alignment of the mechanical axis are reduced, postoperative pain is improved and earlier discharge is facilitated. On the other hand, there are no differences in terms of range of motion, alignment, gap balance, complications, surgical time or functional results.

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PALABRAS CLAVE

Artroplastia total de
rodilla (ATR);
Artroplastia total de
rodilla asistida por
robot (ATRar);
Robótica;
Actualización

Situación actual de la robótica en cirugía protésica de rodilla, ¿una tecnología que ha venido para quedarse?

Resumen La cirugía robótica es una técnica quirúrgica que va en aumento. El objetivo de la artroplastia total de rodilla asistida por robot (ATRar) es el de proveer al cirujano de una herramienta para ejecutar de forma precisa los cortes óseos de acuerdo con una planificación quirúrgica previa para restablecer la cinemática de una rodilla primitiva y el balance de partes blandas, pudiendo aplicar de forma precisa el tipo de alineación que escojamos. Además, la ATRar es una herramienta muy útil para la formación.

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Dentro de las limitaciones, encontramos la curva de aprendizaje, la necesidad de equipos específicos, los costes elevados de adquisición de los dispositivos, en algunos sistemas el aumento de radiación y que cada robot está ligado a un tipo específico de implante.

Los estudios actuales muestran que con la ATRar disminuyen las variaciones de alineación del eje mecánico, mejora el dolor posoperatorio y se facilita un alta más precoz. Por otro lado, no muestran diferencias a nivel de rango de movimiento, alineación, balance de gaps, complicaciones, tiempo quirúrgico o resultados funcionales.

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Introduction

The history of robotics

The Spanish Royal Academy (RAE for its initials in Spanish) defines Robot as “a programmable electronic machine or engineering which is able to manipulate objects and carry out diverse operations”.¹

The term “robotic surgery” refers to the use of programmable devices which are able to carry out a wide variety of surgical tasks.²

Robotic technology has been used in other specialties to improve the precision of surgical dissection and to improve postoperative recovery.³

In orthopaedic surgery different robotic systems have been used. The first available robot for total knee arthroplasties (TKA) and total hip arthroplasties (THA) was Robodoc, currently TSolution-One® (Curexo Technology, currently THINK Surgical Inc., Fremont, CA, U.S.A.) in 1992⁴ (Fig. 1). Later, Mako or *The Robotic Arm Interactive Orthopedic System* (MAKO Surgical Corporation), manufactured by Stryker Orthopaedics, was approved for use by the Food and Drug Administration (FDA) in 2008 (Fig. 2). Subsequent to these systems, currently available is the OMNIBotic® (previously PRAXIM *Robotic-assisted navigation*) (Corin, Tampa, FL, U.S.A.) approved in 2017 by the FDA,⁵ Navio PFS (Blue Belt Technologies, Plymouth, MN, U.S.A.), distributed by Smith & Nephew approved in 2018 by the FDA (Fig. 3) and its update *Real Intelligence CORI* (CORI) *CORI Surgical System* (Blue Belt Technologies, Plymouth, MN, U.S.A.) approved in 2020 by the FDA (Fig. 4) and the ROSA system *knee robotic surgical system* (Medtech Sa, Montpellier, FR) approved for use by the FDA in 2019 (Fig. 5). VELYS™ *Robotic-Assisted Solution* (Depuy Synthes) received FDA approval in January 2021 (Fig. 6), and in China the use of the HURWA *robot-assisted TKA system*⁶ was approved.

The main objective of robotic-assisted total knee arthroplasty (RA-TKA) is to provide the surgeon with a tool to make accurate bone incisions in accordance with a prior surgical plan (preoperative and/or intraoperative, depending on the system used) and to re-establish the kinematics of the knee and soft tissue balance).²

Prior to robotic-assisted surgery different navigation systems were used. The two systems, navigated TKA and assisted TKA present with the following differences.

Differences between navigated TKA and RA-TKA

Navigation-assisted arthroplasty was introduced some three decades ago with expectations of improving the precision of prosthetic component alignment, reducing the incidence of complications and improving functional recovery.^{7,8} This navigation involves the use of computerised systems which offer us intraoperative information in real time concerning the anatomy and kinematics of the knee during surgery. This anatomic osseous map of the patient's knee can be obtained preoperatively using computerised tomography (CT) in the case of navigation based on images, or intraoperatively using the intraoperative mapping of anatomic osseous points of reference in a generic model of the knee joint, in imageless navigation.³

Navigation provides specific anatomic data of the patient with recommendations for bone resection and optimum positioning of the implant, but the computer systems neither actively control nor restrict function, or the surgeon's movements.^{2,3,9}

Unlike navigated total arthroplasty, RA-TKA involves the use of software to convert anatomic information on the patient's knee into a virtual three-dimensional reconstruction.^{7,10,11} The surgeon uses this information to pre and/or intraoperatively plan, calculating bone resection and selecting the positioning and optimum size of the implants.^{10,11} A robotic intraoperative device helps to execute this specific preoperative patient plan with a high level of precision.^{2,3,9,12}

Types of robotic devices

Depending on the level of control the robotic device provides, the robotic assistants are classified into active or semi-active systems and may be “closed” if this only allows us to work with a specific type of implant or manufacturer, or “open” if this allows us to work with different implants.¹³

RA-TKA may be used with images or may be imageless. In all systems, the computer mathematically interprets the data obtained from the surgical field and then displays the information on resection plans, alignment grades and measurements, and flexion and extension spaces on the monitor.¹⁴

Active robotic systems work autonomously to produce planned femoral and tibial bone resections. The surgeon



Figure 1 TSolution-One®.⁴⁵

supervises the bone resection and may activate an emergency deactivation button if necessary. The surgeon uses these systems during surgery, positioning retractors to protect peri-articular soft tissues and then ensures the length of a fixed device. The robot then independently executes the planned bone resections.^{2,3,9}

Semi-active robotic systems allow the surgeon to maintain general control over the bone resection and implant positioning, but provide immediate intraoperative information to limit deviation from the initial surgical plan. These semi-active systems may be with or without preoperative



Figure 2 MAKO.⁴⁶

images and may have visual, tactile and sound sensors to control positioning, strength and bone incisions.^{2,3,9,15}

Types of robotic surgery alignment

There are currently different approaches to the extremity alignment objective after implantation of a TKA.^{16,17} Regardless of the approach or type of alignment chosen by the surgeon, the robot enables us to carry out the preoperative planning in a precise and reproducible manner, since we are freely able to modify the position of the implant up to 6 degrees, between movements and rotations, controlling ligament and soft tissue balance at all times.

Strong points and limitations

Strong points of RA-TKA compared with conventional TKA (cTKA)

The robotic-assisted technique is clearly advantageous for preoperative planning, and in evaluation of changes in intraoperative planning. Prediction on alignment, space balance and axes outcomes is more precise.¹⁰ The RA-TKA technique increases the precision of bone resection, reduces poor positioning of implants and enables an intraoperative ligament balance control.¹³ RA-TKA is also a highly useful training tool,^{9,18} since it provides in situ, virtual viewing of how spaces and alignment change with the positioning of our chosen implant.

From a clinical viewpoint, it seems that robotics is associated with greater control of soft tissues. In one cadaveric study, and in several in vivo studies, lower peri-articular tissue damage was observed in RA-TKA vs cATR.^{11,19,20}

Limitation

The RA-TKA method is not exempt from errors. The surgeon has to know the predetermined configuration values



Figure 3 Navio PFS.⁴⁷



Figure 4 CORI surgical system.⁴⁸

of the equipment they are using. The bone references must be appropriately acquired, this being the stage of the highest source of technical errors in the mapping of the knee. Other possibilities of error may occur in incisions which, depending on the system used, are assisted to a greater or lesser extent. Furthermore, the possibility of errors during the cementing and definitive implant placement phases still exists, as it does with the conventional technique.¹²

Some studies generally report that the re-establishment of the mechanical axis is more reliable in RA-TKA procedures, based on intraoperative measurements of resection plans, compared with cTKA.³

Another important factor is the learning curve, between 7 and 20 cases of RA-TKA,³ although in two studies this learning curve had no obvious negative effect on the precision of the positioning of the femoral and tibial implants nor on the planned mechanical axis.^{5,21,22} Once this learning phase of increased time in surgery²³ has passed but the implant precision positioning has not been affected, work flow and time in surgery are comparable to those of conventional TKA technique.^{5,21}

Limitations also include the fact that most closed systems need specific equipment, with high acquisition and installation costs of devices and in some systems (e.g., MAKO®), an increase in radiation, 4.8 ± 3 mSv (equivalent to 48 chest X-rays),^{24,25} due to the need for a preoperative CT scan.

Most robotic systems require the placement of pins and trackers in the tibia and femur which, depending on the system, involves two incisions separate from the main surgical site and which may lead to soft tissue or bone problems.^{26–28}

Analysis of costs

Robotic-assisted prosthetic surgery is associated with major installation and maintenance costs, software updating, in addition to preoperation images and increase in surgery time during the learning phase.^{5,3} In one article by Kayani et al., they calculated that these costs were between 400,000 and 1.5 million dollars.^{5,3}

In the short term, the published studies on RA-TKA suggested that the initial capital investment could be regarded as compensated by the reduction of analgesia con-



Figure 5 Rosa knee system.⁴⁹

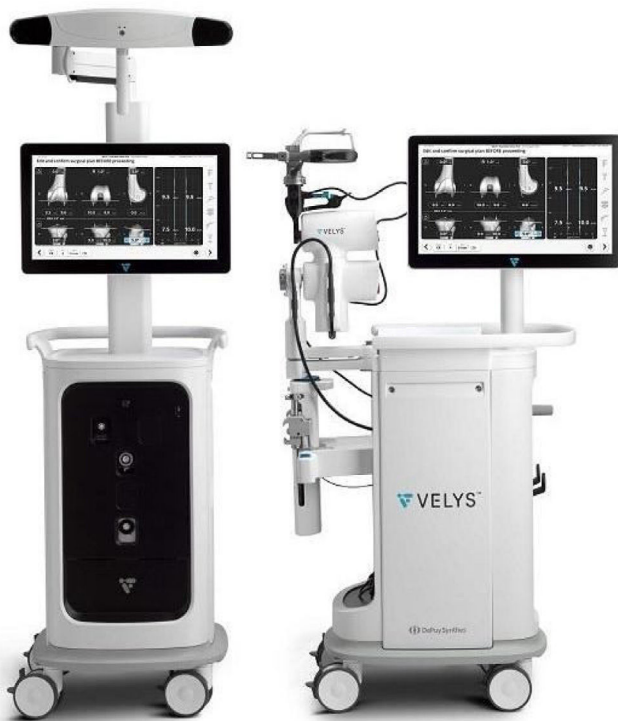


Figure 6 VELYS™.⁵⁰

sumption, the potential to improve the patient reported outcomes measures (PROMs), reducing the mean hospital stay, and reducing the possibility of carrying out an outpatient arthroplasty.³

Cost estimates have been made by type of procedure. Increased costs are entailed for RA-TKA compared with cTKA (based on images: they would increase by approximately \$2600 per prosthesis, and not based on images this would be \$1530).²⁹ Moreover, an analysis of the Markov model has been made in which it has been estimated that RA-TKA could be a profitable procedure in terms of quality adjusted life year (QALY) if a minimum of 253 cases per year were performed.³⁰ In another study, it was estimated that currently it should be possible to avoid 131 cases of prosthesis revision cases in the RA-TKA group, to balance costs out in both groups (RA-TKA vs cTKA) (Tompkins reference). Another study estimated that RA-TKA were cost effective when the annual revision rates were below 1.6% and with a higher post-operative quality of life, particularly when the volume of RA-TKA was above 24 cases/year.³¹ There is a lack of long-term studies to assess whether these costs would remain stable or fall due to possible price reduction of the devices over time and/or whether it could really be proven that revision rates and functional outcomes are better in RA-TKA than in cTKA.^{5,32}

Clinical, radiological and functional outcomes: RA-TKA vs. cTKA

There are currently relatively few medium or long-term studies that analyse the impact of RA-TKA on clinical outcomes and implant survival.⁵

Robotic-assisted prosthetic surgery reduces the mechanical axis alignment variations. In other words, a difference greater than $\pm 3^\circ$ with respect to the neutral axis, being 0% in the robotic group vs. 24% in the conventional group.³³

Radiologically more outliers were found in the mechanical axis, in the re-establishment of the joint space and in the alignment of the components in coronal and sagittal planes using the conventional technique than in the robotic-assisted technique.^{7,34}

Siebert et al. found that after RA-TKA patients presented with less inflammation and oedema in a retrospective study.³⁵ Kayani et al. reported that patients with RA-TKA had less postoperative pain, less need for analgesic salvage and lower rehabilitation time compared with cTKA.³⁶ Another study by Kayani et al. showed that in RA-TKA there was a lower need for medial liberation in correctable and fixed varus deformities, that the femoral and tibial incisions were more precise and that there was lower macroscopic soft tissue injury.¹⁹

Another study found that in RA-TKA there was a 4.5 times lower risk of requiring forced mobilisation under anaesthesia than in cTKA.³⁷

In a systematic review Ren et al. reported better outcomes in RA-TKA on the Knee Society Score (KSS) and Western Ontario and McMaster Universities Arthritis Index (WOMAC) at six months follow-up.³⁸

In a randomised clinical trial comparing cTKA vs. RA-TKA with a minimum follow-up of 10 years, Kim et al. found no differences on the evaluation scales, aseptic loosening, overall survival or complications.³⁹

In the study published by Song et al. no differences were found regarding the range of movement level of the function assessed from the scales such as WOMAC, KSS or Hospital for Special Surgery Knee Score (HSS knee score). Neither were any differences found in complications, mechanical postoperative axis (planned at 0°), or in the femoral tilt in the coronal and sagittal plane, or in the femur and tibia bone incisions. What they did find was that there were no outliers (defined as the difference $\geq \pm 3^\circ$ with respect to that planned) radiologically in the RA-TKA group ($n = 0$) compared with the cTKA group ($n = 12$).⁴⁰

In a meta-analysis published in 2020, in addition to alignment differences, HSS scale differences were found at the end of follow-up, with a lower blood loss and an increased time in surgery in RA-TKA, but no clinically relevant differences were found in the evaluation scales.³⁴ Another meta-analysis adds differences in favour of RA-TKA with regards to postoperative pain, postoperative rehabilitation and earlier discharge.³ Lastly, in the Agarwal et al. meta-analysis differences in the HSS and WOMAC scales were found, but not for range of movement or in the KSS scale.⁴¹

Despite these outcomes, from the increase in precision and the good radiological results, RA-TKA did not have higher medium or long-term outcomes compared with cTKA.^{5,3}

Although RA-TKA has been shown to be successful in the short term, long-term evaluation of implant survival, patient satisfaction and revision arthroplasty rates will determine the value of robotic technology in TKA.⁵

Discussion

TKA is a well-established and highly effective treatment for symptomatic osteoarthritis of the knee. It improves the patient's quality of life, increasing their functional capacity and reduces pain.

Between 80% and 89% of patients are satisfied after a TKA. These percentages remain constant, regardless of the improvements in implants and the protocolisation of procedures, resulting in between 11% and 20% of patients dissatisfied with outcome.^{14,42,43}

The greatest future challenge is to improve outcomes and patient satisfaction. To do this, robotics is promising as it is able to improve soft tissue control and increase the control and precision of implant positioning.

Prospective, comparative and long-term studies are currently lacking to confirm whether these improvements have a positive impact on medium and long-term outcomes.

Future challenges

Possible future improvements include implant cost reduction, due to the option for open system availability, more ergonomic implants to improve efficiency and operation times, the reduction in robot size and the elimination of the need for sensors with pins.

Following the theory of Rogers,⁴⁴ the innovators and early adopters will be those who have to demonstrate with evidence that this technology either delivers all its promised benefits or is just another technology mostly driven by industry.

As robotic technology continues to develop, it is necessary to conduct long-term studies that assess the survival of implants and complications, together with the evaluation of function and the satisfaction of both patients and surgeons.

Provided that data acquisition is correct, we are hoping that big data and machine learning will allow us to resolve as of yet unresolved doubts. For this it is important that, as surgeons, we work to establish clinically relevant questions and know how to use these data. It will also be important to elucidate who the owner of these data is (patient, industry, health centre or national registries) and who may analyse these data so that posterior use is not subject to commercial interest bias. Perhaps in the future these big data will help both surgeons and patients to personalise and choose the best type of implant, the best ligament balance, and the best alignment in each case, thereby obtaining the best functional outcomes and greatest satisfaction for each individual patient.

Conclusions

On the one hand, RA-TKA means performing TKA with high precision and reproducibility, reducing variability with our

pre or intraoperative plan compared with cTKA. We are able to control spaces and balance intraoperatively, thereby leading to better functional rehabilitation and reducing hospital stay.

However, we cannot ignore the added costs at present, the increase in radiation in some cases, and the learning curve associated with this new technique.

With regards to quality of life, functional outcomes, complications and implant survival, existing data up until now are not yet able to confirm if theoretical benefits long term will compensate for the limitations and decide whether this technology is here to stay.

Level of evidence

Level of evidence II.

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Conflict of interests

The authors have no conflict of interests to declare.

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