ROSA Robotic-Assisted Total Knee Replacement

Andrés Zuain, Julián Costantini, Carlos Yacuzzi, Matías Costa Paz
Knee Sector, Orthopedics and Traumatology Service, Hospital Italiano, Autonomous City of Buenos Aires, Argentina

ABSTRACT
Total knee replacement is a procedure with excellent outcomes as long as the objectives of alignment and ligament balance are met. Postoperative comfort and well-being are achieved through a suitable implant for each patient and the correct positioning of the prosthesis. The ROSA robotic system uses information collected before and during surgery, and provides the surgeon with the necessary tools to reproduce the specific anatomy of each patient. In this way, personalized implants are achieved based on the anatomical landmarks of each individual and planning based on specific biometric data.
Keywords: ROSA; robotics; robotic-assisted TKR
Level of Evidence: IV

Reemplazo total de rodilla asistido por robot ROSA

RESUMEN
El reemplazo total de rodilla es un procedimiento con excelentes resultados siempre y cuando se cumplan los objetivos de alineación y balance ligamentario. El confort y bienestar posoperatorio se logra mediante un implante adecuado para cada paciente y el correcto posicionamiento de la prótesis. El sistema robótico ROSA utiliza información recolectada previamente a la cirugía y durante la misma, y le otorga las herramientas necesarias al cirujano para reproducir la anatomía específica de cada paciente. De esta manera, se logran implantes personalizados basados en los reparos anatómicos de cada individuo y una planificación a partir de datos biomètricos concretos.
Palabras clave: ROSA; robótica; RTR asistido
Nivel de evidencia: IV

INTRODUCTION

The main objectives in total knee replacement (TKR) surgery are the restoration of limb alignment, the correct positioning of the prosthetic components, and proper ligament balance. With proper alignment and kinematics of the knee through a correct surgical technique, TKR can achieve excellent functional outcomes. In the literature, there are reports of up to 20% of patient dissatisfaction with the postoperative outcome. Pain, instability, and limited range of motion are the most common symptoms.[1,2] With the conventional technique, alignment values of 3° or more from the neutral axis have been observed.[3-5] For this reason, in recent years, technologies have been developed to improve the precision of bone cuts and location of components.[6-9] These techniques, in principle, are associated with less need for soft tissue release. These advances, coupled with ROSA robot-assisted surgery, have proven effective in achieving more precise and reproducible alignment, which in turn leads to better results and greater patient satisfaction.

The development of robot-assisted surgery is closely related to the technological advances of the last 20 years, beginning with computer assistance and navigation in the early 2000s. Different types of robotic systems have been designed with various characteristics, such as robot autonomy, the need for prior 3D planning, the use of cutting guides or a built-in saw.[10,11]

Received on May 18th, 2022. Accepted after evaluation on September 15th, 2022 • Dr. ANDRÉS ZUAIN • andres.zuain@hospitalitaliano.org.ar ID https://orcid.org/0000-0001-5904-3847
How to cite this article: Zuain A, Costantini J, Yacuzzi C, Costa Paz M. ROSA Robotic-Assisted Total Knee Replacement. *Rev Asoc Argent Ortop Traumatol* 2022;87(6): 838-850. https://doi.org/10.15417/issn.1852-7434.2022.87.6.1579

The ROSA robot assistant is a new, recently introduced system applied to TKRs. Previous systems available on the market differ from it in terms of the method of use (some have the saw built into the robot, for example). During the last decade, these systems have demonstrated their efficacy and safety,[12] but also some difficulties for the surgeon in terms of handling, since their action is restricted to predetermined limits.[13-15] Thus, the surgeon may have the feeling of not being in control of the procedure or being limited with certain movements.

The new assistant presented here is intended to keep the surgeon active, performing the cut while the robotic arm maintains the guide at the location defined in the pre-operative plan at all times. This can be considered robot assistance, since the surgeon remains in charge of the procedure and is supported by this intelligent robotic instrument. It was introduced in March 2019, and since then, its use has spread throughout the world. The abbreviation ROSA stands for "Robotic Surgical Assistant"; this equipment is capable of placing the guides in the ideal position, allowing the surgeon to perform the procedure with high precision and reproducibility (Figure 1). It can be used without previous images or based on radiographs of the patient, which are then converted to a 3D model of the knee. This, together with the analysis of intraoperative ligament balance, allows for personalized prosthetic replacements.

At Hospital Italiano, we have begun to use this technology to achieve better results in our joint replacement surgeries. As objectives of this work, we will describe the concept and the surgical technique of the ROSA robot, showing a case surgically treated with the robot in the hospital. We will highlight its advantages and limitations and we will review what has been reported so far regarding ROSA in the scientific literature.

Figure 1. ROSA robot

ROSA CONCEPT

The goal during the development of the ROSA technology was to keep the surgeon active and in the main stage of surgery. With this system, the surgeon has control of the saw and performs the cuts, while the robotic arm, equipped with a cutting guide, locates and maintains it in the correct position, with high efficiency and reproducibility. After intraoperative planning, the robot is positioned with its guide, according to the surgical plan, to perform the distal femur and proximal tibia cuts, and determines the position of the 4-in-1 cutting guide.

The robotic arm has three modes of action: automatic, collaborative and static. In automatic mode, when the robot is away from the surgical field, the robot moves independently. As it gets closer to the knee and the surgical field, the robot switches to collaborative mode. In this mode, the surgeon collaborates with the robotic arm, exerting a gentle force on the guide until it is placed in the cutting plane on the bone to be resected. In this stage, the movement of the robotic arm is restricted to the cutting plan, but it accompanies and adapts to any movement of the knee. Then, the cutting position of the guide is verified by observing the cuts to be made on the screen, it is fixed with pins, and then the robot switches to static mode, in which the surgeon will be allowed to make the different cuts. Correct cuts can be obtained with a conventional saw blade due to the rigidity of the robotic arm. After the cuts are made, the pins are removed and the robot returns to collaborative mode to make the next cut. The ultimate goal is to achieve a fluid surgical rhythm, increasing the efficiency, safety, and reliability of the cuts made compared to the conventional technique. ROSA is designed to assist the surgeon in cutting both the femur and the tibia, in the sizing of the implants to be used and their positioning (including the rotation of the femoral component), and in the ligament balance.[16]

Surgical technique

The robotic system has two options to approach the case and plan it: it can use a virtual 3D model that comes from the panoramic radiographs that were previously taken from the patient, or no images at all, exclusively basing itself on the anatomical landmarks acquired intraoperatively.

In the first case, standard radiographs are taken on the patient, which are then converted to a 3D model of the knee.[17,18] These radiographs are conventional, adding a calibrated marking (one Velcro positioned on the patient's thigh and another on the ankle) (Figure 2). These images are used to create the 3D model that will serve as planning for the surgeon. With this technique, the size and positioning of the prosthetic components are already available in this step.

Figure 2. Radiographs taken with calibrated marking, from which the 3D model is obtained for preoperative planning.

For the second option, radiographs are taken preoperatively in the same way as for the conventional technique. Intraoperative planning is based on bone landmarks and ligament balance, information collected at the beginning of the procedure. Both options have proven to be highly effective.

Configuration

The ROSA robotic system comprises two main parts, which are located on each side of the surgical field. One is a robotic unit consisting of the robotic arm and a touch screen, and the other is an optical unit, which includes an infrared camera detached from a robotic arm and a touch screen (Figure 3). ROSA's universal cutting guide is located at the end of the arm of the robotic system. Different implants compatible with the system can be used (Persona/NexGen/Vanguard, Zimmer, Biomet). Both the robotic arm and the optical unit, as well as the instruments and the patient's knee, are connected by infrared vision.

Figura 3. Robotic arm with cutting guide (**A**) and optics (**B**).

The surgeon and the robot are located on the same side of the surgical field and the vision system is placed on the opposite side (Figure 4). The first step is to set up the robot in relation to the patient's knee and then calibrate the robotic arm with the optics.

Figure 4. Positioning of the robot in the operating room.

Recording and planning

The procedure with the robot requires the installation of two rigid elements, one in the femur and one in the tibia, as in most robotic systems. These elements, called 'trackers', can be placed inside or outside the incision, depending on the surgeon. They should be positioned far enough from the knee to avoid any conflict between the instrumentation during surgery, and the tibial tracker should be distal enough not to interfere with the placement of the tibial component.

Once the trackers are placed on the bone, the femoral and tibial landmarks are obtained. First, the location of the center of the femoral head is established, capturing 14 different hip positions along its circumduction. The mechanical axis of the femur is determined by the center of the femoral head and the distal entry point of the femoral canal. The remainder of the distal femur landmarks comprise the medial and lateral distal femoral condyles and the medial and lateral epicondyles. The posterior condyles are landmarks for the posterior condylar axis, and the anterior and posterior trochlear groove reflects Whiteside's line. The anterior cortex gives us the size of the femoral component and its position, and determines if notching is taking place. The mechanical axis of the tibia is determined by the medial and lateral to distal malleoli and by the entry point to the tibial intramedullary canal. The references for tibial rotation are the middle third of the anterior tuberosity of the tibia and the insertion of the posterior cruciate ligament. The bone cuts to be made in the medial and lateral plateau are also obtained. An important step at this point is not to perforate the articular cartilage with the pointer when taking these landmarks.

The next step consists of verifying ligament laxity by performing stress in varus and valgus, at different points of knee flexion. The most important values are those taken with the knee in extension and at 90° flexion. Laxity can also be assessed at 30°, 45°, 60° and 120° of flexion. The values obtained will serve to guide the placement of the prosthesis in the different planes, the sizes of the implants and, consequently, the ligament balance. This evaluation of the ligament balance can be carried out before planning, but after the approach and resection of the osteophytes, during the making of the cuts with a spacer (if necessary), or at the end of the procedure with the trial or definitive implant. It can be done at any time to adapt the plan, if desired. The surgeon may also decide not to assess the ligaments and perform the procedure using a technique based exclusively on bone cuts.

Once the bone landmarks have been collected and the ligament laxity evaluation has been carried out, the surgeon decides the final planning according to his or her preferences. During this planning, many parameters are determined: the size of the femoral and tibial components, the orientation of the bone cuts (distal, anterior, posterior, and tibial femurs), and their thickness, based on all the information provided. Predictive values of the final gaps and alignment are obtained (Figure 5).

Figure 5. The orientation of the bone resections and the position and size of the implants allow adjustment of the gaps in extension and flexion, and the final alignment of the entire limb. Modifying all of these values will give instant feedback on alignment and gaps.

Bone resections

Once the planning is done, the screen will continue with the "Resection Panel". The sequence of cuts, whether tibia or femur first, is at the surgeon's preference. By choosing one or the other on the touch screen, ROSA will automatically move the robotic arm toward the knee. Once it reaches the surgical field, the collaborative mode is activated and the surgeon guides the cutting guide to the position where it should be placed, while ROSA remains in the indicated coronal and sagittal planes, and at the planned resection height. The values of the cuts to be made are instantly obtained on the screen, so that they can be checked against the planned values (compensating for any movement of the knee). Once the guide is aligned with the cut, it is fixed with two pins and the resection is performed using a conventional saw (Figure 6). Once carried out, a validation system is supported on the bone to confirm that it was in accordance with what was planned. Each cut can be modified at any time, if necessary.

Figure 6. When the guide is attached to the bone and the robot is locked in position, a firm construct is achieved, upon which the surgeon is allowed to make bone cuts.

The conventional technique aims to achieve a neutral alignment of the operated lower limb (within a range of 0 to 3°), placing the femoral and tibial components perpendicular to their respective mechanical axes. The bone cuts are made independently of each other (usually starting with the distal femur), but have a close relationship, since both the cut of the distal femur and that of the posterior condyles must be parallel to the tibial cut. Ligament balance is obtained by sequential soft tissue release to balance the medial and lateral compartments, both in flexion and extension. The stability of the knee replacement is based on the correct positioning of the prosthetic implants and the adequate gaps throughout the range of motion.

We describe the case of a 76-year-old patient who underwent a left TKR with the assistance of the ROSA robot. Upon physical examination, the patient reported knee pain, secondary to tricompartmental knee osteoarthritis (Figure 7). She had good preoperative ranges of motion, with predominantly internal pain, with a varus malalignment of approximately 12°.

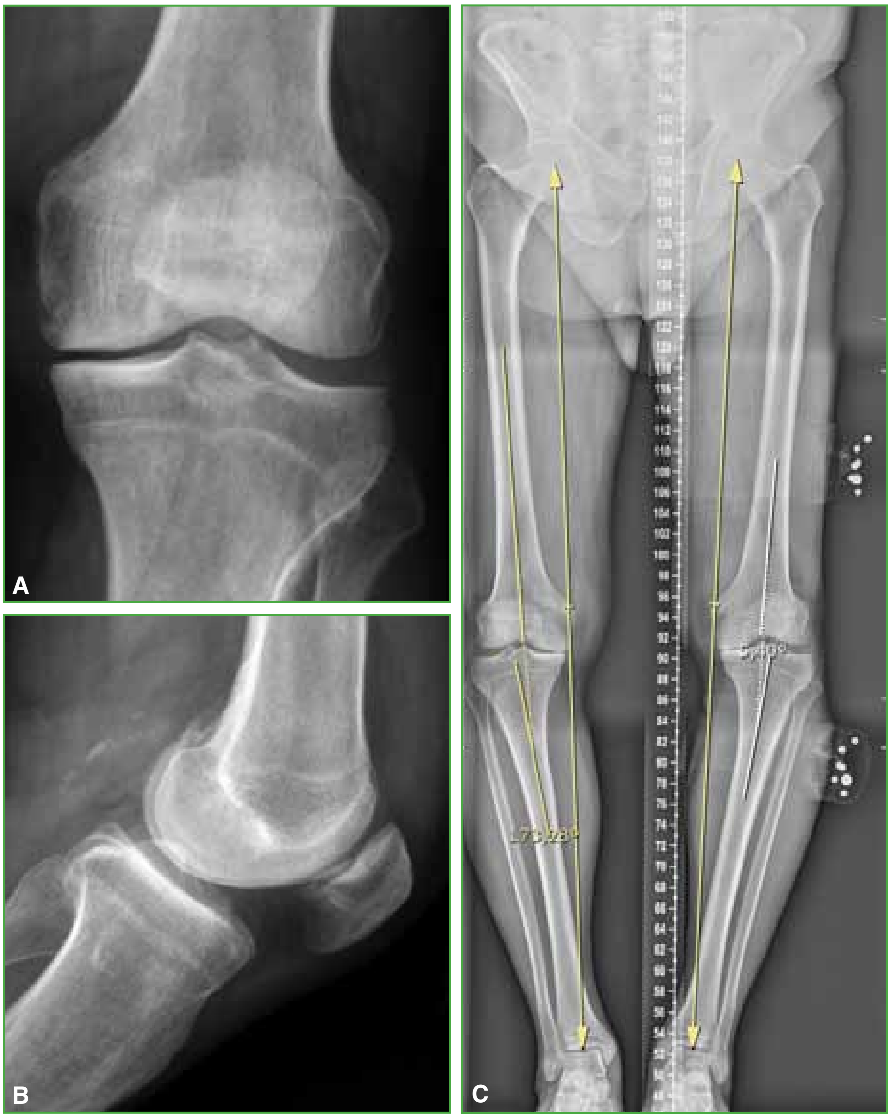

Figure 7. **A and B**. Anteroposterior and lateral knee radiographs. **C**. Preoperative scanogram.

Once the trackers are installed and the medial parapatellar approach is performed, the menisci are completely resected together with the cruciate ligaments. The medial osteophytes are resected, which opens the gap medially and generates sufficient release to balance both compartments. At this point, the previously described bone landmarks are taken. Preoperative ligament laxity and range of motion are assessed and the femur cuts are first planned on the screen. In the genu varum replacement technique, typically, the amount of bone removed in the tibia will be greater from the lateral plateau than from the medial, greater in the medial to distal femoral condyle, and greater from the medial side in the posterior condyles. All cuts are made and the gap in extension is measured with a spacer. The screen is checked to corroborate the presence of residual varus or a flexion contracture. The soft tissues are released sequentially, if necessary. The knee is flexed and the ROSA cutting guide is placed to make the rest of the femur cuts. Rotation is verified by aligning it with the transepicondylar axis, which presents external rotation of 3° in relation to the posterior condylar axis. The cuts are made as planned. Trial components are placed and a final assessment is made, considering full range of motion, alignment, and stability in flexion and extension. If all this is satisfactory, the final components are placed (Figures 8 and 9).

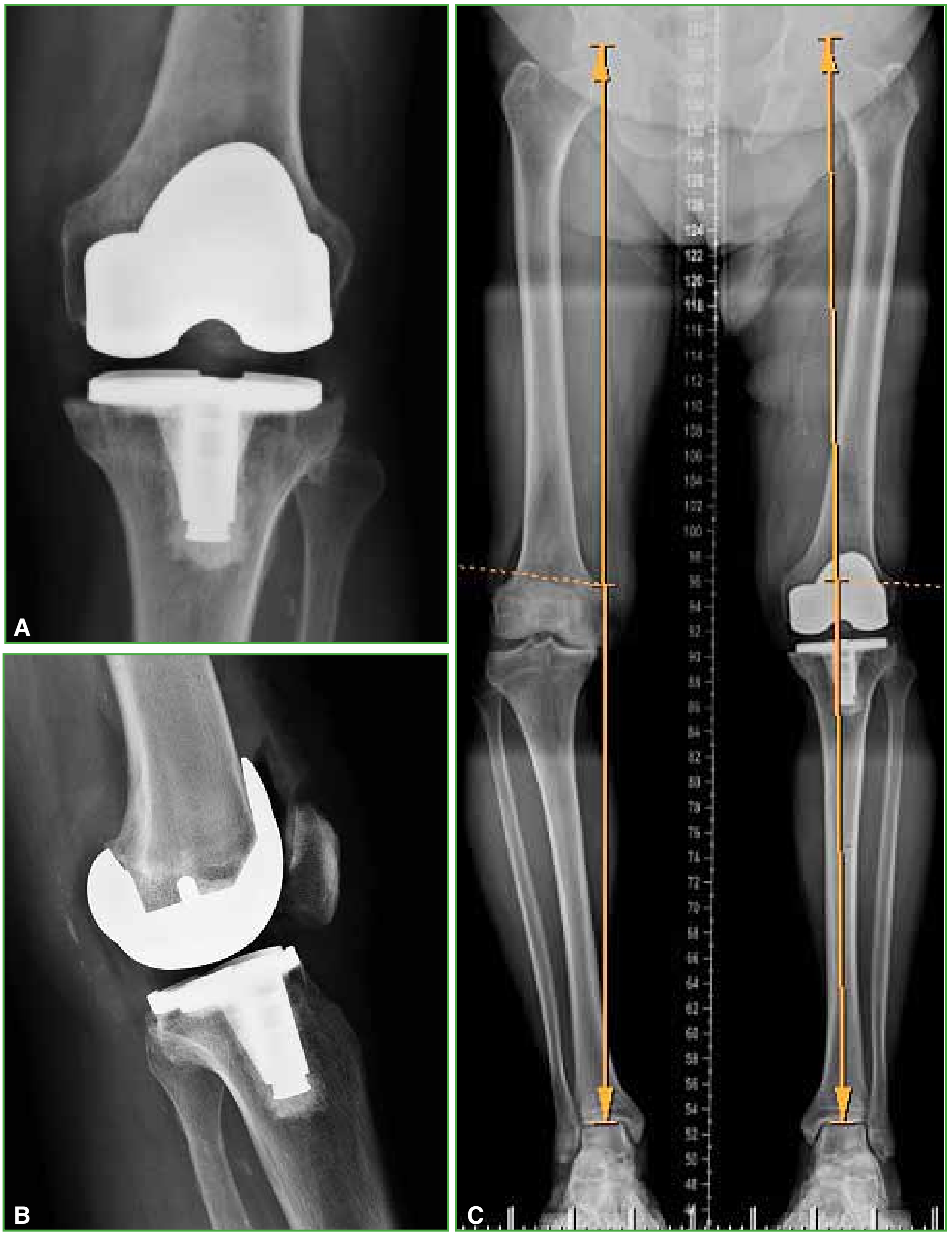

Figure 8. A and B. Anteroposterior and lateral knee radiographs. **C.** Postoperative scanogram.

Figure 9. Final evaluation (with trial or definitive components) of range of motion and ligament balance in flexion and extension.

Indications

The current indications for the use of the ROSA robot are unicompartmental prostheses and complex primary replacements such as those presenting large malalignments, sequelae of fractures, or extra-articular deformities. It is currently being used in conventional primary replacements to achieve good robot handling, although the ultimate goal is to use it in the aforementioned cases, since robotic assistance would help to achieve better alignment results and ligament balance in those complex cases.

Advantages and limitations

The characteristics of this system are its simplicity and that it allows maintaining a smooth surgical rhythm, as well as minimizing the set-up time of the robot, which, in turn, provides high accuracy rates for the orientation of the components and the bone cuts.

Among the advantages, the following can be mentioned:

- Use of radiographs for planning (less expensive, less radiation than CT, and simpler for the patient). These radiographs are weight-bearing, so they represent a more functional position on which to plan. It is not essential to perform them, since ROSA has the option of planning by taking intraoperative parameters as a reference (this can be considered another advantage).
- Collaborative robotic system, where the robot keeps the cutting guide in the precise place and the surgeon is in constant control and with the tactile sensation of the saw and the rest of the instruments. ROSA's aim is to complement the surgeon's skills and not to replace them. The sequence of the cuts, the positioning of the implant, the mechanical axis and the ligament balance are individualized for each patient, at the preference of the surgeon.
- Easy to manipulate and does not require much time to set up.
- A single cutting guide, easily manipulated with three modes of action.
- Greater accuracy and precision in bone cuts.
- Less blood loss (by not invading the intramedullary canals with the cutting guides).
- Less damage to soft tissues (the exposure is the minimum necessary for the visualization of the pins by the robot).
- Shorter hospital stay.
- Faster post-surgical recovery
- Possibly better functional recovery and range of motion.

Regarding the limitations, we can mention the following:

- Significant cost (not affordable for all surgeons).
- The improvement in the functional outcomes of patients operated with robotic assistance has not yet been demonstrated.
- Learning curve (especially for intraoperative planning). The information provided on the screen in this step is abundant and can be confusing. Experience is needed in this step: at the moment, if the planning is not appropriate, there is no automatic re-adjustment by the system.
- Complications specific to the robotic system, such as pin breakage or pin location fracture, are rare and can be avoided with a better placement technique.

This robotic system is recent and there are still no clinical studies with sufficient follow-up to report functional outcomes. However, two cadaveric studies have reported the accuracy of this technique. Parratte et al. have demonstrated the accuracy and reproducibility of this device in a series of 30 cadaveric knees.[19] The authors compared three different measurements: the preoperative planning of the bone cuts to be made with ROSA, the actual size of the cut made, and the thickness of bone resected for each cut. To standardize the procedure, a final alignment of 0° was targeted, making cuts perpendicular to the mechanical axis of both the femur and tibia in the coronal plane. The cuts made using the ROSA system had a high precision. Regarding the angulation of the cuts, there were no significant differences between the planned and measured values, except for femoral flexion, which had an average difference of less than 1°. No differences were observed in the values of the resected bone thickness, except in the distal cut of the medial femoral condyle and in the medial tibial plateau. The average difference in the final alignment of the limb was less than 1°.

In another cadaveric study, Seidenstein et al. compared the accuracy of ROSA with the conventional technique for TKRs.[20] Two groups were analyzed: one made up of 20 knees operated with the conventional technique and the other of 14 knees operated with ROSA assistance. All the cuts made were validated with the ROSA device designed for that specific function and the bone resections were measured with a caliper. The accuracy of the angulation values of the cuts improved significantly in the group operated with robotic assistance. For these, the difference was less than 0.6°. Regarding the measurement of the resected bone, the values were all less than 0.7 mm. 100% of the values in the group operated with ROSA were within 2 mm of what was planned, except for the distal femur resection (93%). The robotic system led to exact bone resections with less error, compared to the conventional technique. The distal femur cut was less accurate than the rest, but still more accurate than with the standard technique. These results coincide with those reported by other robotic systems. Clinical studies are underway to compare functional outcomes and patient satisfaction.

WHAT IS AHEAD OF US?

With the advent of robotic surgery and new technologies, procedures tend to be simplified, more precise, and their results become more reliable, which represents an important step towards improving functional outcomes and patient satisfaction after TKR. Analyzing all the variables that influence this (in addition to the surgical technique), such as the specific characteristics of each patient, the deformities, the preoperative clinical situation, we can realize the importance of each of them, and how they modify the postoperative results. Considering all these points (pre-, intra- and postoperative), the surgeon could improve his or her daily practice and decision-making. Regarding robotic-assisted surgery itself, the use of this system will lead the surgeon to learn from each of the procedures and achieve a better performance in the following surgery.

CONCLUSIONS

ROSA is a semi-autonomous robotic assistance system with specific characteristics compared to previous systems of this type. The objective of this surgical assistant is to improve the accuracy and reliability of bone cuts and ligament balance, without replacing the surgeon's hand in any of the steps. Preliminary results from this system proved to be reproducible and accurate for performing TKRs.

Conflict of interest: The authors declare no conflicts of interest.

J. Costantini ORCID ID: https://orcid.org/0000-0001-8900-6254
C. Yacuzzi ORCID ID: https://orcid.org/0000-0002-7732-7883
M. Costa Paz ORCID ID: https://orcid.org/0000-0002-8217-1086

REFERENCES

1. Halawi MJ, Jongbloed W, Baron S, Savoy L, Williams VJ, Cote MP. Patient dissatisfaction after primary total joint arthroplasty: the patient perspective. *J Arthroplasty* 2019;34(6):1093-6. https://doi.org/10.1016/j.arth.2019.01.075
2. Palazzo C, Jourdan C, Descamps S, Nizard R, Hamadouche M, Anract P, et al. Determinants of satisfaction 1 year after total hip arthroplasty: the role of expectations fulfilment. *BMC Musculoskelet Disord* 2014;15:53. https://doi.org/10.1186/1471-2474-15-53
3. Hetaimish BM, Khan MM, Simunovic N, Al-Harbi HH, Bhandari M, Zalzal PK. Meta-analysis of navigation vs conventional total knee arthroplasty. *J Arthroplasty* 2012;27(6):1177-82. https://doi.org/10.1016/j.arth.2011.12.028
4. Bollars P, Boeckxstaens A, Mievis J, Kalaai S, Schotanus MGM, Janssen D. Preliminary experience with an image-free handheld robot for total knee arthroplasty: 77 cases compared with a matched control group. *Eur J Orthop Surg Traumatol* 2020;30(4):723-9. https://doi.org/10.1007/s00590-020-02624-3
5. Liow MHL, Xia Z, Wong MK, Tay KJ, Yeo SJ, Chin PL. Robot-assisted total knee arthroplasty accurately restores the joint line and mechanical axis. A prospective randomised study. *J Arthroplasty* 2014;29(12):2373-7. https://doi.org/10.1016/j.arth.2013.12.010
6. Smith AF, Eccles CJ, Bhimani SJ, Denehy KM, Bhimani RB, Smith LS, et al. Improved patient satisfaction following robotic-assisted total knee arthroplasty. *J Knee Surg* 2021;34(7):730-8. https://doi.org/10.1055/s-0039-1700837
7. Figueroa F, Wakelin E, Twiggs J, Fritsch B. Comparison between navigated reported position and postoperative computed tomography to evaluate accuracy in a robotic navigation system in total knee arthroplasty. *Knee* 2019;26(4):869-75. https://doi.org/10.1016/j.knee.2019.05.004
8. Hampp EL, Chughtai M, Scholl LY, Sodhi N, Bhowmik-Stoker M, Jacofsky DJ, et al. Robotic-arm assisted total knee arthroplasty demonstrated greater accuracy and precision to plan compared with manual techniques. *J Knee Surg* 2019;32(3):239-50. https://doi.org/10.1055/s-0038-1641729
9. Mullaji A, Kanna R, Marawar S, Kohli A, Sharma A. Comparison of limb and component alignment using computer-assisted navigation versus image intensifier-guided conventional total knee arthroplasty: a prospective, randomized, single-surgeon study of 467 knees. *J Arthroplasty* 2007;22(7):953-9. https://doi.org/10.1016/j.arth.2007.04.030
10. Bautista M, Manrique J, Hozack WJ. Robotics in total knee arthroplasty. *J Knee Surg* 2019;32(7):600-6. https://doi.org/10.1055/s-0039-1681053
11. Sires JD, Craik JD, Wilson CJ. Accuracy of bone resection in MAKO total knee robotic-assisted surgery. *J Knee Surg* 2021;34(7):745-8. https://doi.org/10.1055/s-0039-1700570
12. Marchand RC, Sodhi N, Anis HK, Ehiorobo J, Newman JM, Taylor K, et al. One-year patient outcomes for robotic-arm-assisted versus manual total knee arthroplasty. *J Knee Surg* 2019;32(11):1063-8. https://doi.org/10.1055/s-0039-1683977
13. Kayani B, Konan S, Tahmassebi J, Pietrzak JRT, Haddad FS. Robotic-arm assisted total knee arthroplasty is associated with improved early functional recovery and reduced time to hospital discharge compared with conventional jig-based total knee arthroplasty: a prospective cohort study. *Bone Joint J* 2018;100-B(7):930-7. https://doi.org/10.1302/0301-620X.100B7.BJJ-2017-1449.R1
14. Biant LC, Yeoh K, Walker PM, Bruce WJM, Walsh WR. The accuracy of bone resections made during computer navigated total knee replacement. Do we resect what the computer plans we resect? *Knee* 2008;15(3):238-41. https://doi.org/10.1016/j.knee.2008.01.012
15. Casper M, Mitra R, Khare R, Jaramaz B, Hamlin B, McGinley B, et al. Accuracy assessment of a novel image-free handheld robot for total knee arthroplasty in a cadaveric study. *Comput Assist Surg (Abingdon)* 2018;23(1):14-20. https://doi.org/10.1080/24699322.2018.1519038

16. Batailler C, Hannouche D, Benazzo F, Parratte S. Concepts and techniques of a new robotically assisted technique for total knee arthroplasty: the ROSA knee system. *Arch Orthop Trauma Surg* 2021;141(12):2049-58. https://10.1007/s00402-021-04048-y
17. Massé V, Ghate RS. Using standard X-ray images to create 3D digital bone models and patient-matched guides for aiding implant positioning and sizing in total knee arthroplasty. *Comput Assist Surg (Abingdon)* 2021;26(1):31-40. https://doi.org/10.1080/24699322.2021.1894239
18. Lustig S, Fleury C, Goy D, Neyret P, Donell ST. The accuracy of acquisition of an imageless computer-assisted system and its implication for knee arthroplasty. *Knee* 2011;18(1):15-20. https://doi.org/10.1016/j.knee.2009.12.010
19. Parratte S, Price AJ, Jeys LM, Jackson WF, Clarke HD. Accuracy of a new robotically assisted technique for total knee arthroplasty: A cadaveric study. *J Arthroplasty* 2019;34(11):2799-803. https://doi.org/10.1016/j.arth.2019.06.040
20. Seidenstein A, Birmingham M, Foran J, Ogden S. Better accuracy and reproducibility of a new robotically-assisted system for total knee arthroplasty compared to conventional instrumentation: a cadaveric study. *Knee Surg Sports Traumatol Arthrosc* 2021;29(3):859-66. https://doi.org/10.1007/s00167-020-06038-w