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Robotic-assisted partial knee surgery performances: A 10-year follow-up retrospective study

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Abstract

Purpose: Robotic surgery has emerged as an advanced technique for facilitating knee prosthesis implantation, especially in cases requiring high precision. However, due to the recent introduction and implementation of this approach, long-term data on its outcomes remain limited in the literature. This study aims to assess implant survival, complications and reoperation rates resulting from robotic arm-assisted partial knee arthroplasties, with a long-term follow-up period.

Methods: A retrospective analysis was conducted on 236 patients who underwent robotic arm-assisted partial knee arthroplasty, with a minimum follow-up of 10 years. Clinical outcomes were evaluated, focusing on implant survival, complications, reoperation rates, and overall patient satisfaction. The study primarily examined medial unicompartmental knee arthroplasty (UKA), with Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC), Knee Society Score (KSS) Part 1 and KSS Function scores assessed preoperatively and at the last follow-up.

Results: Among the 236 patients, 212 were available at the last follow-up; satisfaction rates were overall positive, with 210 patients reporting being 'satisfied' or 'very satisfied'. Both WOMAC score and KSS showed statistically significant improvement postoperatively, both globally and in UKA patients specifically.

Conclusions: The study demonstrates excellent long-term satisfaction rates, improved clinical outcomes and implant survival with minimal surgical morbidity. These findings offer valuable insights into the effectiveness of robotic arm-assisted knee arthroplasty.

Level of Evidence: Level III, retrospective comparative study.

KEYWORDS

10-year follow-up, KSS, MAKO, robotic system, UKA, WOMAC

Abbreviations: KSS, Knee Society Score; PKR, Partial knee replacement; PROM, patient-reported outcome measure; ROM, range of motion; TKA, total knee arthroplasty; UKA, unicompartmental or unicondylar knee arthroplasty; WOMAC, Western Ontario and McMaster Universities Osteoarthritis Index.

INTRODUCTION

Partial knee replacement (PKR) has been introduced as a viable alternative to total knee arthroplasty (TKA) in case single compartments of the knee are involved in a degenerative process [9, 29, 33, 38, 46]. Under the common name of PKR then fall the unicompartmental or unicondylar knee arthroplasty (UKA), which can in turn be implanted on the medial or on the lateral condyle (taking the respective name), and the patello-femoral joint replacement; these three different implants can then be combined, in order to obtain multicompartmental configurations [17]. Medial UKA is the most commonly performed procedure [7, 8, 16]: this predominance is mainly due to the fact that the medial compartment represents one of the most sensible ones in the joint and is thus one of the most prone to complications [7, 40, 41]. Compared to TKA, medial UKA is less invasive and more respectful of the knee's native kinematics, while reducing blood loss and the need for transfusions, accelerating the return of function, reducing the use of pain medications, improving the range of motion (ROM), shortening the duration of the hospitalization and simplifying future revision scenarios [13, 14, 28, 48]. Despite the excellent functional results achieved for the majority of patients [4, 13, 31, 39, 46], long-term survival is still at the centre of debate [31, 37]; it is however to specify that the main complications after UKA implantation, namely femorotibial osteoarthritis of the contralateral compartment and loosening of the tibial implant, are in the majority of cases due to an incorrect implant placement [3, 28, 43]. In fact, one of the biggest challenges regarding the ultimate success of the procedure is the technically demanding nature of the surgery, which is therefore subject to more complications than a TKA operation: [31] inadequate prosthesis alignment has indeed been associated with early UKA failure and is likely to contribute to the higher revision rate seen with UKA compared to TKA (4.6% vs. 1.4% at 3 years) [42]. Moreover, scientific evidence suggests that surgeons performing low volumes of UKA present higher revision rates, reflecting the complexity and the challenging learning curve of this surgery [1, 6, 9, 32, 34, 47]. Robotic-assisted surgery has therefore recently been introduced as a tool to help the surgeon in performing this kind of complex operation in a more controlled environment, and many different robotic systems are nowadays available on the market [19, 35]. Thanks to the recent widespread of this technique, an increasing number of studies on assisted UKA became available in the literature, and they overall reported improved lower limb alignment, soft tissue balance and implant placement when compared to conventional surgery [42, 43]. The use of robotics in partial knee reconstruction surgery appears then to be a potential tool to decrease the difficulties for low-volume surgeons [2, 29], and overall it can allow to achieve better clinical outcomes, implant survival and minimal (or even absent) surgical morbidity. However, despite these encouraging findings, the novelty of these devices poses challenges in assessing their long-term outcomes. Consequently, literature on this topic remains scarce, and when available, it often involves cohorts of small patient numbers [42].

To address this gap, the current retrospective study aims to gather and present 10-year follow-up data on a considerable number of patients who underwent PKR at our clinic with the use of robotic assistance. Our hypothesis is that this technique will achieve a higher survivorship rate compared to the traditional approach, which typically reports between 80% and 90% survival at 10 years [23, 26, 27, 36], and therefore the data analyzed will be used to verify this claim.

MATERIALS AND METHODS

A total of 236 consecutive patients were involved in this retrospective study.

Inclusion criteria for the study were based on standard guidelines for unicompartmental knee arthroplasty, and included ligamentous stability, deformities not exceeding 10° of varus or valgus, a weight limit of 120 kg, absence of inflammatory pathologies, osteoarthritis affecting only one compartment, preserved ROM, and no age restrictions.

Each patient underwent a robotic-assisted PKR in the period between 27 January 2011 and 18 December 2012. In detail, 208 patients received a medial UKA (88%), 11 a lateral UKA (5%) and 17 a bicompartmental PKR (7%). The decision to implant a UKA was based on clinical criteria, such as the location of pain, as well as instrumental assessments including x-rays and magnetic resonance imaging. In the case of bicompartmental PKR, involving medial UKA combined with patellofemoral joint replacement, the decision was made when visible wear of the femoral condyle was visible on imaging studies, which is clinically symptomatic. In some cases, this wear may be confirmed intraoperatively and addressed in real time.

All the surgeries were performed with the assistance of the Interactive Robotic Arm System (RIO; MAKO Stryker). It is noteworthy to mention that the patients presented in this study represent some of the first cases of robot-assisted UKAs performed in Italy, if not the first ones themselves.

The RIO is a semi-active haptic-guided robotic system (Figure 1) and offers active assistance in performing the bone resections themselves, providing a series of haptic feedbacks to the surgeon and modulating the activity of the cutting tool accordingly; this approach is therefore different from computer-assisted navigation, as this latter provides mainly passive

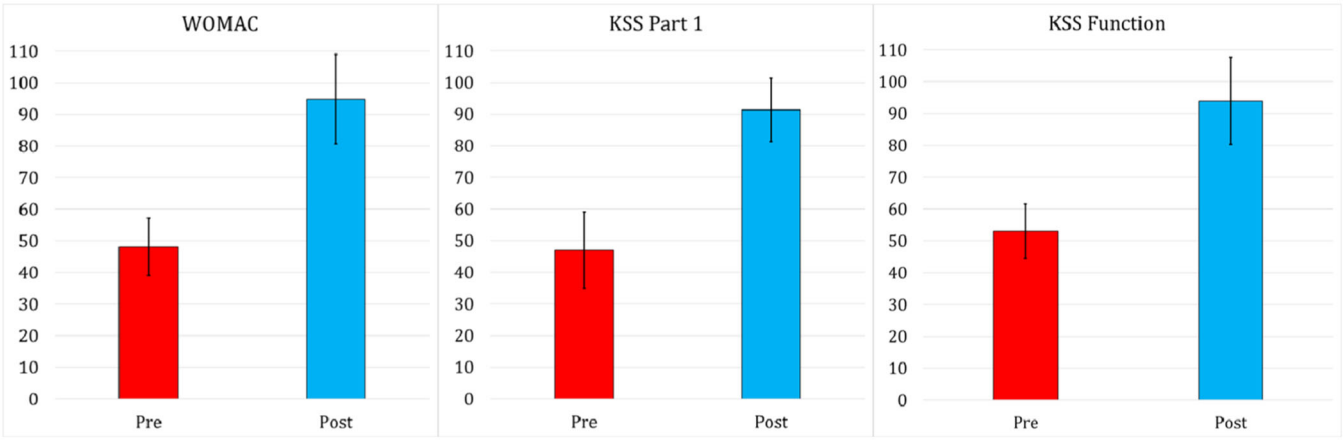

FIGURE 1 Pre- and post-operative average WOMAC scores, KSS Part 1 and KSS Function (all patients involved). KSS, Knee Society Score; WOMAC, Western Ontario and McMaster Universities Osteoarthritis Index.

guidance and feedback. For each patient, preplanning was required in order to establish the resection plan, defined according to the implant selected and the bone geometries. This planning was then used during the procedure to instruct the robotic system: the semi-active robot synchronizes thus the drill's position according to the operational boundaries and, as the drill approaches the limits of the planned resection (in terms of location or depth), the system automatically decelerates it or retracts it into the handle, thereby mitigating the risk of excessive bone removal. This technology allowed therefore the surgeon to perform bone resections within precise parameters, offering feedback and controls that minimize errors enhancing precision.

Before the operation, each patient was evaluated to assess the level of severity of their condition. In order to quantify this evaluation, three scores were extracted from the surveys: Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) [5], Knee Society Score (KSS) Part 1 (encompassing questions related to pain, function and quality of life, resulting in an overall assessment of the patient's experience) [21] and KSS Function (a subscale of the KSS, focused specifically on the physical function of the knee, assessing activities such as walking, stair climbing, and other daily tasks to provide a targeted measure of functional improvement after surgery) [21].

These same scores, when possible, were then obtained at the patients' 10-year follow-up.

A post-hoc analysis was performed for the three scores using G*Power 3.1.2 [11, 12], first considering all the patients and then focusing on the medial-UKA group alone. In detail, the effect size was evaluated independently for each parameter using the pre-operative and post-operative averages and standard deviations. An alpha error of 0.05 (a universally accepted threshold) was chosen, and the sample size was determined based on the numerosity of the two groups.

The statistical analysis of the data was then performed on both the pre-operative and follow-up results. Firstly, the normality of the distributions was checked with a Normal Probability Plot; after having obtained positive outcomes from this test, the data were analyzed to evaluate the mean and standard deviation for each score. Comparisons in terms of pre-operative/follow-up and implant configuration were then performed to assess eventual significant differences.

RESULTS

Out of 236 patients who underwent surgery, 212 (89.83%) were available to be evaluated for the 10-year follow-up, 9 patients (3.81%) died for reasons unrelated to the surgery, 5 patients (2.11%) required revision surgery and were operated in the meantime, 4 patients (1.69%) developed pathologies unrelated to the surgery (one case of Alzheimer, two cases of Parkinson and one case of brain ischaemia) and were incapable for participation to the follow-up, and 6 patients (2.54%) were unreachable and therefore were not evaluated.

Survivorship was assessed through radiographic follow-up and patient interviews, where clinical conditions were evaluated. Patients demonstrating positive outcomes at the 10-year follow-up were thus included in the survivorship data, and interviews with the relatives of deceased patients were also conducted to verify the condition of the operated knee in the period prior to death, demonstrating positive results. Patient-reported outcome measures (PROMs) were incorporated into the scoring system used in our follow-up assessments, therefore the analysis in this study focused specifically on these scores, as they already represent a comprehensive evaluation based on

PROM data. Among the patients interviewed at the follow-up, 99% stated that their expectations regarding the surgery had been met and that they would undergo the reference surgical procedure again: 202 patients reported feeling very satisfied, 8 were satisfied and 2 were neither satisfied nor dissatisfied. At the final follow-up, three cases of loosening of the tibial component and two cases of painful prostheses (that required total revision surgery) were observed.

It is important to note that one case of femoral fracture and two cases of tibial fracture occurred approximately one month after surgery, in correspondence to the pin holes required for fixing the marker arrays. These complications were treated with a femoral plate fixation, a tibial intramedullary nail, and a plaster cast, respectively.

Moreover, six cases of persistent synovitis were noted, which were reduced to four cases after various arthrocentesis and anti-inflammatory therapy with steroids. In 2 cases, cultures tested positive for *Staphylococcus aureus* and *Staphylococcus epidermidis*. These cases were addressed through a DAIR procedure, involving thorough debridement, replacement of the polyethylene insert and a targeted antibiotic therapy for 4 weeks.

A radiographic progression of wear in the other compartments was furthermore observed in 26 patients at the 10-year follow-up; however, this progression was not clinically relevant.

Addressing the statistical analysis of the scores, a statistical power exceeding 0.95 was identified for all parameters and groups investigated, reflecting the substantial improvements in these scores; the normality test results returned a positive outcome, therefore justifying the statistical approach used. The comparison between pre-operative and 10-year follow-up scores, comprehending all the patients, returned clinical improvements up to 70% of the score values. Statistically significant increases ($p < 0.05$) were thus overall observed for WOMAC, KSS Part 1 and KSS Function (see Table 1, graphically represented in Figure 1).

Focusing on the patients who received a medial UKA implant, which accounted for 88% of the total cohort, the scores demonstrated a similar trend, with statistically significant increases ($p < 0.05$) observed across all score measures (Table 2).

TABLE 1 Pre- and post-operative scores (all patients involved).

Score	Pre-operative	Post-operative
WOMAC	48 ± 9	95 ± 14
KSS Part 1	47 ± 12	91 ± 10
KSS Function	53 ± 9	94 ± 14

Abbreviations: KSS, Knee Society Score; WOMAC, Western Ontario and McMaster Universities Osteoarthritis Index.

TABLE 2 Pre- and post-operative scores (medial UKA patients only).

Score	Pre-operative	Post-operative
WOMAC	48 ± 9	95 ± 9
KSS Part 1	47 ± 12	91 ± 10
KSS Function	53 ± 14	94 ± 14

Abbreviations: KSS, Knee Society Score; UKA, unicompartmental or unicondylar knee arthroplasty; WOMAC, Western Ontario and McMaster Universities Osteoarthritis Index.

DISCUSSION

In this retrospective study, clinical outcomes, patient survival and satisfaction rates were evaluated for robotic-assisted UKA at a minimum of 10 years post-operatively. The results of this evaluation showed that patients in this series exhibited excellent implant survival, with a 94% satisfaction rate (considering all the patients were still alive or unreachable at the time of the follow-up), along with significant improvements in clinical outcomes, as indicated by substantial enhancements in KSS and WOMAC score related to pain, stiffness, and function. These positive outcomes were consistent with the observed improvements in knee flexion and alignment. Notably, only five cases required revision to TKA, with three of these procedures performed at another facility. This study stands out due to the high volume of medial unicompartmental prosthesis implants performed using robotic assistance, making it one of the largest reported in the literature with long-term follow-up.

Our findings align with other significant studies, such as the long-term study performed by Zambianchi et al. [45], which returned a slightly lower follow-up rate but a comparable survival rate; the prospective multicenter study by van der List et al. [28] also reported excellent implant survival at short-term (98.8%) with robotic arm-assisted UKA, as well as excellent satisfaction rates, similar to the ones found in this study. Additionally, 92% of their patients were either very satisfied or satisfied, a satisfaction rate highlighted by the authors as the highest reported in any large cohort study to date [28]. Kleeblad et al. [25], in another prospective multicentric study of robotic arm-assisted UKAs, reported a survival rate of 97.5%, with 91% of patients very satisfied or satisfied at mid-term follow-up. Regarding satisfaction, the rates in our study are among the highest reported for robotic-assisted or conventional UKA [15, 42]. Specifically, 88.9% of our patients were very satisfied or satisfied at an average follow-up of 10 years. Slightly higher satisfaction rates have been reported by Wong et al. [44] (98%), but it is considered that ‘excellent’ or ‘good’ satisfaction rates generally range between 77.5% and 94.5% in short to medium terms, after conventional UKA [16].

A common agreement among all these studies consists in the deduction that one possible explanation for the excellent survival and satisfaction rates of robotic arm-assisted UKA is the ability to precisely control surgical variables [2, 16, 29]. Our results, in conjunction with previous data, indicate that accurate implant placement and optimal lower limb alignment can lead to excellent implant survival and high patient satisfaction rates. The accuracy of robotic systems and the precision of robot-assisted UKA compared to conventional UKA, particularly in terms of implant placement and knee kinematics, have already been demonstrated in previous studies [4, 10, 20, 22, 24, 29, 31, 45].

The results of our study regarding the alignment and positioning of the implant agree with the existing literature, showing maintenance of the achieved parameters even at an average follow-up of more than 10 years.

The present study has, however, several limitations to be reported. First, it is a single-centre study, which may limit the generalizability of the findings to other institutions or patient populations. Concerning the population, it is to be reported that phenotype characterization was not performed on the patients involved, and therefore the decision-making was based on the surgeons' experience alone; the Hirschmann et al. [18] and MacDessi et al. [30] classifications, used for the phenotype characterization, were indeed introduced only years after the surgeries addressed in this study: it was therefore not possible to categorize knee using these frameworks. Additionally, multiple surgeons performed the procedures analyzed and the distribution of patients across the different surgeons was not uniform, which could introduce potential bias. Finally, the types of PKR implanted were not uniformly distributed; medial UKA accounted for 88% of cases, which indeed impacted the outcomes (as highlighted by the similarity among the global results and the ones focused on the medial UKA cohort) and can limit comparisons with other PKR types. This uneven distribution reflects the lower overall demand for other types of PKR, making it challenging to gather substantial data for each of these types individually. Consequently, a global approach was adopted to analyze the overall results of all PKR types together, which nonetheless yielded highly satisfactory outcomes.

CONCLUSIONS

At a minimum of 10 years post-surgery, robotic arm-assisted unicompartmental knee arthroplasty demonstrated remarkable long-term outcomes, with high rates of implant survival and 94% patient satisfaction. As highlighted by the scores achieved at the long-term follow-up, patients experienced significant improvements in pain, stiffness and overall knee function, along with the restoration of knee ROM. These findings can, therefore, reinforce the belief that robotic arm-assisted UKA is not only a safe and effective technique but also one that delivers durable results over the long term.

AUTHOR CONTRIBUTIONS

Piergiuseppe Perazzini, Paolo Sembenini, Francesco Alberton and Andrea Cochetti were involved in the surgeries and the patient surveys performed prior to the study. Piergiuseppe Perazzini and Edoardo Bori contributed to the study's conception. Piergiuseppe Perazzini, Edoardo Bori and Bernardo Innocenti contributed to the design of the analysis. Edoardo Bori and Bernardo Innocenti contributed to the statistical analysis of the data and the interpretation of results. Edoardo Bori contributed to the first draft, and all the authors contributed to its refinement to achieve the first submission and then contributed to the revision process leading to the resubmission.

CONFLICT OF INTEREST STATEMENT

Piergiuseppe Perazzini: Consultant for Stryker. The other authors declare no conflicts of interest.

DATA AVAILABILITY STATEMENT

The data supporting the findings of this study are available from the corresponding author upon reasonable request.

ETHICS STATEMENT

This study was conducted in accordance with institutional ethical standards. Due to its retrospective design, specific ethical approval was not required according to local regulations. Patient consent was waived for this study due to its retrospective nature, in alignment with institutional guidelines.

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