Acta Biomed 2017; Vol. 88, Supplement 2: 54-59 DOI: 10.23750/abm.v88i2 -S.6514

Original article

Robotic-arm assisted partial knee arthroplasty: a single centre experience

Andrea Marcovigi, Francesco Zambianchi, Dario Sandoni, Elisa Rivi, Fabio Catani
Department of Orthopaedic Surgery, Azienda Ospedaliero-Universitaria Policlinico di Modena, Univerity of Modena and Reggio-Emilia, Modena, Italy

Summary. *Background and aim of the work:* UKA has proven to be an effective surgical procedure, but its survivorship is still negatively affected by inaccuracy in component component positioning, implant and limb alignment. Robotic surgery has been introduced in order to minimize such technical errors. The aim of the present paper was to evaluate clinical and surgical outcomes after a 3 years' experience of robotic assisted UKA with the Mako Robotic Arm. *Methods:* Seventy-three patients undergoing UKA with robotic instrumentation (65 medial UKAs, 8 lateral UKAs) and with a clinical follow-up of 3 -37 months were included in the present study. A complete clinical evaluation with KOOS, FJS-12 and SF-12 was administered to all patients pre and post operatively. Post-operative HKA angle and surgical time were also recorded. *Results:* Mean post-operative KOOS score was 81.32 (SD 17.19), while the mean FJS-12 score was 75.51 (SD 30.12) and the mean SF-12 Physical Score 42.25 (SD 9.97). 91% to 88% of post-operative results were considered satisfactory. Only 1 UKA failure was reported (1.3%) caused by peri-prosthetic infection. In medial UKAs mean postoperative HKA angle in extension was 3.9° varus (SD 2.5°), with no case of overcorrection; in lateral UKAs mean postoperative HKA angle in extension was 1.9° valgus (SD 1.9°) with 1 case (13%) of overcorrection. Mean skin to skin surgical time decreased from 83.2 minutes (SD 13.0) to 70.0 minutes (SD 10.9) along the learning curve. *Conclusions:* Robotic UKA has provided an improvement both in clinical and technical results, determining satisfactory clinical outcomes and a low risk of post-operative complications. (www.actabiomedica.it)

Key words: knee arthroplasty, robotic surgery, unicondylar, mako, alignment

Introduction

In the recent years unicompartmental knee arthroplasty (UKA) has encountered an increasing popularity due to the encouraging results displayed by literature and national arthroplasty registries.

UKA can determine durable pain relieve and satisfactory clinical results in more than 90% of patients (1, 2); furthermore, modern implant designs and new materials provide a considerable improvement in long-term survivorship making this surgical procedure the gold standard in the treatment of single compartment end-stage osteoarthritis and focal osteonecrosis (3, 4).

It has been calculated that the annual incidence of UKA in the United States is growing at an estimated annual rate of 32.5%; similar data are reported from the National Joint Registry of England and Wales, with an increase of 35% from 2007 to 2016 (5, 6).

Despite its growing success, UKA remains a technically demanding procedure, especially when using less invasive surgical approaches (7).

Many factors could, in fact, jeopardize implant success, from improper patient selection, to surgical errors. In particular, a lack of accuracy in component positioning, soft tissue balance, implant and limb alignment are badly tolerated and could lead to poor clinical results and negatively affect long-term survivorship (8, 9).

In order to improve accuracy of both preoperative planning and implant positioning, new technologies have been applied to the surgical procedure with the introduction of navigation and, lately, robotics (10, 11).

In 2000 Cobb et al. were the first to introduce robotic assistance for UKA implantation with the tactile guide system "Acrobot" and in 2006 reported that mean implant position errors relative to the planned position were respectively 1.1 mm and 2.5° with robotic assistance compared with 2.2 mm and 5.5° obtained with conventional instrumentation (10).

In 2006 the Mako platform was introduced: an haptic-controlled semi-active robotic arm designed to perform UKA for medial and lateral tibio-femoral compartments and for the patello-femoral joint (12).

This system consists of a CT-based technology combined with a navigation module, allowing a preoperative planning of the implant, and an intra-operative, in vivo, control over soft tissue balancing, preparation of tibial and femoral cavities and components positioning (13).

The aim of the present paper was to evaluate clinical and surgical outcomes after a 3 years' experience of robotic assisted UKA with the Mako Robotic Arm.

Materials and methods

Between January 2014 and March 2017, 116 consecutive patients underwent UKA in a single center. All the operations were performed by the senior surgeon.

One hundred-one patients were scheduled for medial UKA, 12 underwent lateral UKA and 3 underwent patello-femoral UKA.

In this retrospective analysis only patients with a minimum follow up of three months and subjected to medial or lateral operations were considered, for a total of 87 patients. Fourteen patients were lost at follow up, leaving 73 patients for study assessment (Tab. 1).

The preoperative protocol performed on every patient included a complete clinical assessment with the following scores: Knee injury and Osteoarthritis Outcome Score (KOOS), Forgotten Joint Score-12 (FJS-12), Short Form physical and mental health summary scales-12 (SF-12). A CT-scan and a long-leg weight bearing anterior-posterior radiograph were also taken (14-16). The CT scan was necessary to reconstruct patient's anatomy and to perform preoperative planning and implant templating, while weight bearing X-Ray were used to perform alignment measurements on the operated and on contralateral lower limbs.

All patients underwent UKA with a mini invasive midvastus approach and with the use of Mako Rio robotic instrumentation to implant the same prosthetic model (MCK Restoris, Mako Surgical Corp - Stryker).

Bi-cortical screw fixation was used for placement of femoral and tibial trackers, and morphing acquisitions of the femur and tibia were performed to match epiphyseal anatomy with the 3D CT models with the Crisis software (Mako Surgical Corp - Stryker) and to obtain the mechanical axis of the limb.

After calibration, a soft tissue balancing assessment was performed and pre-operative planning was eventually modified accordingly, taking record of every modification.

Lower limb Hip-Knee-Ankle angle (HKA) was measured with CAS instrumentation with the knee in complete extension and in complete flexion, before and after component implantation. The HKA angle is the angle between the mechanical axis of femur and mechanical axis of tibia. As a convention the HKA angle may be expressed as its angular deviation from 180° (17).

Table 1. Study Population categorized by involved compartment

Involved compartment	Cases	Age (min -max)	Gender	Mean follow up (Min – Max)
Medial UKA	65	69 (50-83) years	22 M, 43 F	17.7 (3-37) months
Lateral UKA	8	62.6 (50-2) years	3 M, 5 F	17.5 (6-26) months
Total	73	68.2 (50-83) years	25 M, 48 F	17.2 (3-37) months

A complete post-operative clinical assessment (KOOS, FJS-12, SF-12) was administered to patients at a minimum follow up of 3 months after surgery.

Clinical results were considered satisfactory for a post-operative score increase >8 for KOOS, and when >0 for other scores (18).

Every case of early or late post-operative complication such as component loosening, infection or fracture was reported.

Total surgical time (skin to skin) and robotic instrumentation use time were recorded for every patient. Patients were then divided into two groups according to operation date to assess eventual differences in operating time bound to growing surgical experience.

Results

For the 73 involved patients, the mean post-operative KOOS score was 81.32 (SD 17.19), while the mean FJS-12 score was 75.51 (SD 30.12), the mean SF-12 Physical Score 42.25 (SD 9.97) and the mean SF-12 Mental Score was 34.17 (SD 8.52). The mean improvement since preoperative results was respectively 43.56, 60.09, 16.45 and 5.18 points (for complete clinical score dataset see Tab. 2).

Post-operative complications were reported only in 1 case, with the development of peri-prosthetic infection that brought to revision arthroplasty within the first year after UKA, with a survivorship of 98.7%.

In the group of patients treated with medial UKA, mean preoperative HKA angle in extension was 6.6° varus (SD 3.1°)and mean postoperative HKA angle in extension was 3.9° varus (SD 2.5°) with a mean correction of 3.1° (SD 2.2°); none of the patients with varus HKA angle was corrected to valgus.

In the same group mean preoperative HKA angle in flexion was 1.9° varus (SD 2.8°) and mean postoperative HKA angle in flexion was 2.2° varus (SD 3.1°) with a mean correction of 0.1° (SD 2.0°).

In the group of patients treated with lateral UKA, mean preoperative HKA angle in extension was 5.3° valgus (SD 2.6°) and mean postoperative HKA angle

Table 2. Clinical assessment: mean pre-operative and post-operative KOOS, FJS-12 and SF-12 scores. A mean post-operative increase was reported for all scores

	Medial UKA (n= 65)	Lateral UKA (n= 8)	Whole population (n= 73)
KOOS			
Pre-operative	38,01 (SD 14,64)	35,68 (SD 11,14)	37,75 (SD 14,25)
Post-operative	81,32 (SD 16,8)	81,30 (SD 21,44)	81,32 (SD 17,19)
Pre/Post-operative difference	43,31 (SD 22,66)	45,63 (SD 22,11)	43,56 (SD 22,46)
Satisfied	92%	87%	91%
FJS-12			
Pre-operative	15,99 (SD 13,48)	10,8 (SD 10,8)	15,42 (SD 13,25)
Post-operative	76,37 (SD 30,26)	68,58 (SD 29,99)	75,51 (SD 30,12)
Pre/Post-operative difference	60,38 (SD 33,44)	57,77 (SD 35,88)	60,09 (SD 33,47)
Satisfied	89%	87%	89%
SF-12 PS			
Pre-operative	26,03 (SD 4,78)	23,91 (SD 2,4)	25,8 (SD 4,62)
Post-operative	42,34 (SD 9,9)	41,46 (SD 11,2)	42,25 (SD 9,97)
Pre/Post-operative difference	16,31 (SD 10,9)	17,55 (SD 10,62)	16,45 (SD 10,81)
Satisfied	88%	87%	88%
SF-12 MS			
Pre-operative	28,84 (SD 6,5)	30,19 (SD 7,31)	28,98 (SD 6,55)
Post-operative	34,29 (SD 8,68)	33,2 (SD 7,46)	34,17 (SD 8,52)
Pre/Post-operative difference	5,45 (SD 9,2)	3,01 (SD 5,31)	5,18 (SD 8,86)
Satisfied	75%	47%	72%

Table 3. Lower limb alignment: mean preoperative and post-operative lower limb alignment in extension and in flexion, measured with surgical navigation. In extension a slight undercorrection of deformity was obtained both in medial and in lateral UKAs; in flexion mean correction was always lower than 1°. For pre-op and post-op HKA angles we defined positive values as varus and negative values as valgus

	HKA angle in Extension			HKA angle in Flexion		
	Pre-op	Post-op	Correction	Pre-op	Post-op	Correction
Medial UKA (n= 65)	6.6°±3.1°	3.9°±2.5°	3.1°±2.2°	1.9°±2.8°	2.2°±3.1°	-0.1°±2.0°
Lateral UKA (n= 8)	-5.3°±2.6°	-1.9°±1.9°	3.4°±2.4°	-1.9°±2.3°	-1.7°±4.1°	-0.7°±1.8°

in extension was 1.9° valgus (SD 1.9°) with a mean correction of 3.4° (SD 2.4°); in 1 patient a valgus HKA angle was corrected to varus 0.5°.

In the same group mean preoperative HKA angle in flexion was 1.9° valgus (SD 2.3°) and mean postoperative HKA angle in flexion was 1.7° valgus (SD 4.1°) with a mean correction of 0.7° (SD 1.8°). (Tab. 3)

Mean skin to skin surgical time was respectively 76.4 minutes (SD 13.3) in medial UKAs and 77.1 minutes (SD 16.7) for lateral UKAs; mean robotic time was respectively 38.4 minutes (SD 8.0) for medial UKAs and 39.6 minutes (SD 8.4) for lateral UKAs.

Considering whole population skin to skin time averaged 76.5 minutes (SD 13.3) and robotic time averaged 38.5 minutes (SD 8.0). Considering separately the first 36 operated patients and the second 37 operated patients we found respectively skin to skin times of 83.2 minutes (SD 13.0) and 70.0 minutes (SD 10.9) and robotic times of 41.9 minutes (SD 8.2) and 35.2 minutes (SD 6.3). (Fig. 1). The differences between the 2 groups were found significant ($p<0.001$) with a two-tailed T-Test.

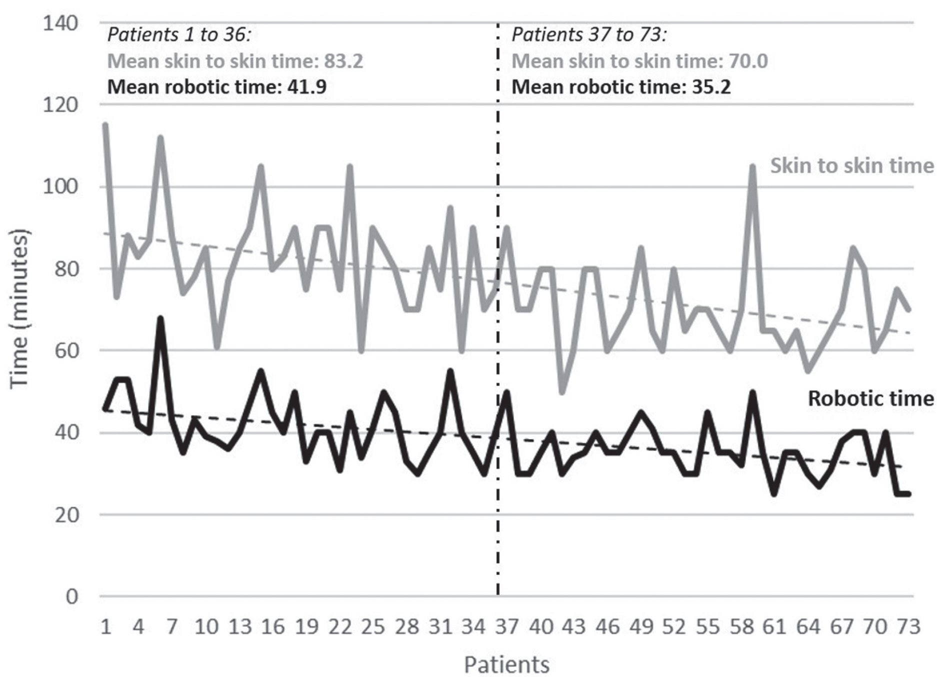

Figure 1. Surgical time (minutes): description of skin to skin time (in grey) and robotic time (in black). It is possible to see, as represented by the linear tendency lines (dashed lines), how surgical times are progressively decreasing. When considering patients from 1 to 36 and from 37 to 73 separately the differences between the 2 groups are always statistically significant ($p<0.001$)

Discussion

In the first large prospective study that has assessed survivorship and satisfaction rate of robotic-assisted UKA, Pearle et al (19) described a survivorship rate of 98.8% with a patients' satisfaction rate of 92%.

A wide variability of results is reported for standard UKAs, with satisfaction rates included between 77.5% and 92% in current literature and from 83% to 88% in national arthroplasty registries; while survivorship at 2-3 years is included between 87% and 98.3% (19-25).

Results achieved in the present study, with a survivorship of 98.7% and a satisfaction rate from 88% to 91%, are similar to the ones reported by Pearle et al. for robotics UKA and slightly superior to the ones reported for standard UKA.

It's been advocated that better clinical results obtained with robotic instrumentation may be bound to the reduction of surgical exposure, altogether with a highest reliability in implant positioning and lower limb realignment (3, 11, 26).

Lower limb alignment was another parameter taken into account in the present study: mean final HKA angle in extension was 3.9° in varus in medial UKAs and 1.9° in valgus in lateral UKAs; in patients with medial OA no case of overcorrection was reported, while in patients with lateral OA overcorrection was reported in 1 case (13%).

While controversies still exist regarding the optimal postoperative limb alignment, literature agrees that overcorrection may lead to accelerated arthritic progression of the uninvolved compartment (27). Our case series have shown similarities with the study from Khamaisy et al. (28) on knee Makoplasty, reporting that the realignment process of the lower extremity may be prone to overcorrection in lateral UKAs more than the medial UKAs, though in present data overcorrection never occurred in medial UKAs while in the cited article a 4% of overcorrections was reported.

The difference may be explained by the fact that limb realignment in robotic surgery with Mako relies on soft tissue balancing and intraoperative planning corrections and could be influenced by surgeon's experience. The soft-tissue guided procedure also permitted to obtain a coronal plane alignment correction in extension, while leaving a physiological alignment in flexion with mean values of correction close to 0°.

Finally, surgical time was reported: a constant improvement has been achieved both in surgical and in robotic time, reducing mean operative times of more than 13 minutes during the learning curve.

One of the more often reported limits of robotic surgery in arthroplasty is the increased surgical time (29); Shankar et al (30) reported a mean skin to skin time of 81.4±25.5 minutes for standard UKAs from a high volume orthopedic center. Present data testify that robotic UKAs could equal and even improve operative times.

The present study has several limitations. First of all, medial and lateral UKAs populations had very different samples, that's why a direct comparison between groups has not been attempted.

A second limit is that follow up times are not homogeneous between patients, but we considered 3 months sufficient as post-operative follow up time even if it could negatively influence clinical outcomes report.

A third limit is that coronal plane alignment report is based only on navigation measures and not on standard radiographs, but on standard X-ray it could not be possible to obtain a reliable alignment in flexion.

Conclusion

In our experience, robotic UKA has provided an improvement both in clinical and technical results, determining satisfactory clinical outcomes and a low risk of post-operative complications.

The soft tissue balancing technique and the in vivo intraoperative evaluation permitted to avoid overcorrection of HKA angle, reducing dramatically the risk of other compartment arthritic progression.

Furthermore, surgical time, often considered as a limit for this type of surgery, has resulted improved even in comparison to standard UKAs.

References

1. Borus T, Thornhill T. Unicompartmental knee arthroplasty. Journal of the American Academy of Orthopaedic Surgeons 2008; 16(1): 9-18.

2. Repicci JA. Total knee or uni? Benefits and limitations of the unicondylar knee prosthesis. Orthopedics 2003; 26(3): 274-7.
3. Lonner JH, John TK, Conditt MA. Robotic arm-assisted UKA improves tibial component alignment: a pilot study. Clinical Orthopaedics and Related Research 2010; 468(1): 141.
4. Palumbo BT, Scott RD. Diagnosis and indications for treatment of unicompartmental arthritis. Clinics in sports medicine 2014; 33(1): 11-21.
5. Riddle DL, Jiranek WA, McGlynn FJ. Yearly incidence of unicompartmental knee arthroplasty in the United States. The Journal of arthroplasty 2008; 23(3): 408-12.
6. National Joint Registry for England and Wales 13th annual report 2016
7. Zambianchi F, Digennaro V, Giorgini A, Grandi G, Fiacchi F, Mugnai R, Catani F. Surgeon's experience influences UKA survivorship: a comparative study between all-poly and metal back designs. Knee Surgery, Sports Traumatology, Arthroscopy 2015; 23(7): 2074-80.
8. Collier MB, Eickmann TH, Sukezaki F, McAuley JP, Engh GA. Patient, implant, and alignment factors associated with revision of medial compartment unicondylar arthroplasty. The Journal of arthroplasty 2006; 21(6): 108-15.
9. Hamilton WG, Collier MB, Tarabee E, McAuley JP, Engh CA, Engh GA. Incidence and reasons for reoperation after minimally invasive unicompartmental knee arthroplasty. The Journal of arthroplasty 2006; 21(6): 98-107.
10. Jenny JY, Ciobanu E, Boeri C. The rationale for navigated minimally invasive unicompartmental knee replacement. Clinical orthopaedics and related research 2007; 463: 58-62.
11. Cobb J, Henckel J, Gomes P, Harris S, Jakopec M, Rodriguez F, Davies B. Hands-on robotic unicompartmental knee replacement. Bone & Joint Journal 2006; 88(2): 188-97.
12. Roche M. Robotic-assisted unicompartmental knee arthroplasty: The MAKO experience. Clinics in sports medicine 2014; 33(1): 123-32.
13. Tamam C, Poehling GG. Robotic-assisted unicompartmental knee arthroplasty. Sports medicine and arthroscopy review 2014; 22(4): 219-22.
14. Roos EM, Roos HP, Lohmander LS, Ekdahl C, Beynnon, BD. Knee Injury and Osteoarthritis Outcome Score (KOOS) – development of a self-administered outcome measure. Journal of Orthopaedic & Sports Physical Therapy 1998; 28(2): 88-96.
15. Behrend H, Giesinger K, Giesinger JM, Kuster MS. The "forgotten joint" as the ultimate goal in joint arthroplasty: validation of a new patient-reported outcome measure. The Journal of arthroplasty 2012; 27(3): 430-6.
16. Gandek B, Ware JE, Aaronson NK, Apolone G, Bjorner JB, Brazier JE, Sullivan M. Cross-validation of item selection and scoring for the SF-12 Health Survey in nine countries: results from the IQOLA Project. Journal of clinical epidemiology 1998; 51(11): 1171-78.
17. Cooke TDV, Sled EA, Scudamore RA. Frontal plane knee alignment: a call for standardized measurement. Journal of Rheumatology 2007; 34(9): 1796-801.
18. Roos EM, Toksvig-Larsen S. Knee injury and Osteoarthritis Outcome Score (KOOS)–validation and comparison to the WOMAC in total knee replacement. Health and quality of life outcomes 2003; 1(1): 17.
19. Pearle AD, van der List JP, Lee L, Coon TM, Borus TA, Roche MW. Survivorship and patient satisfaction of robotic-assisted medial unicompartmental knee arthroplasty at a minimum two-year follow-up. The Knee 2017; 24(2): 419-28.
20. Biswal S, Brighton RW. Results of unicompartmental knee arthroplasty with cemented, fixed-bearing prosthesis using minimally invasive surgery. The Journal of arthroplasty 2010; 25(5): 721-7.
21. Gleeson RE, Evans R, Ackroyd CE, Webb J, Newman JH. Fixed or mobile bearing unicompartmental knee replacement? A comparative cohort study. The Knee 2004: 11(5): 379-84.
22. Saxler G, Temmen D, Bontemps G. Medium-term results of the AMC-unicompartmental knee arthroplasty. The knee 2004; 11(5): 349-55.
23. Schroer WC, Barnes CL, Diesfeld P, LeMarr A, Ingrassia R, Morton DJ, Reedy M. The Oxford unicompartmental knee fails at a high rate in a high-volume knee practice. Clinical Orthopaedics and Related Research 2013; 471(11): 3533-9.
24. The New Zealand Joint Registry. Fourteen year report. January 1999 to December 2012.
25. Robertsson O, Dunbar M, Pehrsson T, Knutson K, Lidgren L. Patient satisfaction after knee arthroplasty: a report on 27,372 knees operated on between 1981 and 1995 in Sweden. Acta Orthopaedica Scandinavica 2000: 71(3): 262-7.
26. Mofidi A, Plate JF, Lu B, Conditt MA, Lang JE, Poehling GG, Jinnah RH. Assessment of accuracy of robotically assisted unicompartmental arthroplasty. Knee Surgery, Sports Traumatology, Arthroscopy 2014; 22(8): 1918-25.
27. Murray DW, Goodfellow JW, O'connor JJ. The Oxford medial unicompartmental arthroplasty. J Bone Joint Surg Br 1998; 80(6): 983-9.
28. Khamaisy S, Gladnick BP, Nam D, Reinhardt KR, Heyse TJ, Pearle AD. Lower limb alignment control: is it more challenging in lateral compared to medial unicondylar knee arthroplasty?. The Knee 2015; 22(4): 347-50.
29. Jacofsky DJ, Allen M. Robotics in arthroplasty: a comprehensive review. The Journal of Arthroplasty 2016; 31(10): 2353-63.
30. Shankar S, Tetreault MW, Jegier BJ, Andersson GB, Della Valle CJ. (2016). A cost comparison of unicompartmental and total knee arthroplasty. The Knee 2016; 23(6): 1016-9.

Received: 13 April 2017
Accepted: 8 May 2017
Correspondence:
Marcovigi Andrea
Via del Pozzo 71 - 41124 Modena, Italy
Tel. +39 059 422 4309
Fax +39 059 422 4313
E-mail: dott.marcovigi@gmail.com