

A Comparative Study of Lower Limb Alignment between MAKO Robot-Assisted and Conventional Unicompartamental Knee Arthroplasty

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Abstract

Backgrounds:

This retrospective study aims to comparatively analyze the lower limb alignment correction capabilities of MAKO robot-assisted surgery and conventional surgery.

Methods

Clinical data of 70 patients who underwent UKA treatment in the Department of Orthopedics, Qingdao University Affiliated Hospital, from January 2022 to November 2023 were reviewed. Among them, 48 patients who underwent MAKO robot-assisted UKA were included in the MAKO robot group, and 22 patients who underwent conventional UKA were included in the conventional group. The preoperative and postoperative lower limb alignment hip-knee-ankle (HKA) angles of the two groups were recorded and subjected to inter-group and intra-group analysis.

Results

Both groups of patients successfully completed the surgeries. The postoperative HKA angle in the MAKO robot group averaged $176.03^{\circ} \pm 3.08^{\circ}$, showing an average correction of $5.13^{\circ} \pm 2.75^{\circ}$ compared to the preoperative angle ($170.09^{\circ} \pm 3.74^{\circ}$), with a statistically significant difference ($t = 12.90, p < 0.05$). In the conventional group, the postoperative HKA angle averaged $175.47^{\circ} \pm 2.40^{\circ}$, demonstrating an average correction of $5.47^{\circ} \pm 2.21^{\circ}$ compared to the preoperative angle ($170.00^{\circ} \pm 2.95^{\circ}$), also with a statistically significant difference ($t = 11.62, p < 0.05$). However, the comparison of postoperative HKA angles and correction degrees between the two groups showed no statistically significant difference ($t = 0.76, p > 0.05$; $t = 0.51, p > 0.05$).

Conclusion

Both MAKO robot-assisted UKA and conventional UKA effectively corrected the lower limb alignment of patients postoperatively. However, compared to conventional surgery, MAKO robot-assisted UKA did not demonstrate a significant advantage in lower limb alignment correction ability.

Introduction

Unicompartmental knee arthroplasty (UKA) is an effective surgical intervention for treating isolated medial compartment osteoarthritis of the knee joint. Compared to total knee arthroplasty (TKA), it offers potential advantages such as reduced intraoperative bleeding, faster recovery, greater bone preservation, fewer perioperative complications, improved functional outcomes, enhanced patient proprioception, and higher patient satisfaction[1–3]. However, compared to TKA, UKA presents a higher revision rate[4, 5],

with postoperative lower limb malalignment being one of the significant contributing factors to UKA failure [6].

Currently, the optimal alignment for UKA remains controversial, but numerous studies have confirmed that maintaining a mild varus alignment of the lower limb postoperatively has good clinical function and better prosthesis survival outcomes[7–9]. However, conventional UKA surgical techniques require high precision, necessitating the surgeon to achieve higher implant positioning and balancing accuracy within a small incision range without damaging ligaments. Therefore, achieving precise alignment during surgery presents a certain level of challenge for young and inexperienced surgeons[10]. In conventional surgery, issues such as excessive soft tissue release, inadequate bone resection, and suboptimal prosthesis positioning often arise due to technical reasons, leading to poor lower limb alignment outcomes postoperatively[11–13]. Poor alignment includes overcorrection and undercorrection. Overcorrection can lead to valgus alignment outcomes closely associated with the progression of osteoarthritis in the lateral compartment of the knee joint. On the other hand, undercorrection can result in excessive varus, leading to complications such as polyethylene wear, knee joint pain, and aseptic loosening. It is evident that poor alignment is a significant factor leading to the revision of UKA [7, 8, 14, 15]. With technological advancements, the emergence of orthopedic computer navigation systems and surgical robots has met the needs of surgical technical deficiencies. Robot-assisted UKA can achieve better soft tissue balance, precise bone cuts, and improved prosthesis positioning, making precise alignment during UKA surgery possible. Consequently, this improves the survival and functional outcomes of UKA [16, 17].

The MAKO robot-assisted system is a semi-automatic robotic assistance system that can perform preoperative planning based on three-dimensional CT reconstructions of the patient's knee joint. It provides real-time monitoring of the surgical process and allows the surgeon to make dynamic adjustments based on the patient's actual condition and individual habits, ensuring the precision of the surgery[18]. Several studies have already demonstrated that MAKO robot-assisted UKA results in favorable prosthesis positioning and survival outcomes compared to conventional methods[19, 20]. However, there is limited analysis of lower limb alignment in patients undergoing fixed-bearing UKA after surgery. This study aims to compare the lower limb alignment outcomes of patients undergoing fixed-bearing UKA with and without MAKO robot assistance and to evaluate the ability of MAKO robot-assisted fixed-bearing UKA in correcting lower limb alignment.

Material and methods

Patients

This study was carried out in accordance with the World Medical Association Declaration of Helsinki. After obtaining approval from the Affiliated Hospital of Qingdao University ethics committee(Ethical approval number:QYFY WZLL28411Z), this study conducted a retrospective analysis of patients who underwent knee joint UKA at the Affiliated Hospital of Qingdao University from January 2022 to

November 2023, based on the following criteria. Inclusion criteria: (1)Initial medial compartment UKA surgery;(2)Use of a fixed-platform prosthesis on the tibial plateau. Exclusion criteria: (1)Use of a mobile-platform prosthesis;(2)Patients undergoing lateral compartment UKA;(3)Patients with missing preoperative or postoperative bilateral full-length weight-bearing X-rays. A total of 70 patients were included in the study and were divided into two groups based on whether they underwent surgery assisted by the MAKO robotic system: the MAKO robotic group and the conventional group, with 48 and 22 cases, respectively. There were no statistically significant differences in age, sex, laterality, and BMI between the two groups ($P < 0.05$, Table 1).

Table 1
Comparison of preoperative baseline data between the two patient groups

Group	n	Age($\bar{x} \pm s$, year)	Sex(men/women)	laterality(left/right)	BMI($\bar{x} \pm s$, kg/m ²)
MAKO robotic group	48	61.79 $\pm$ 7.25	10/38	28/20	26.41 $\pm$ 4.01
Conventional group	22	61.05 $\pm$ 5.86	6/16	12/10	26.24 $\pm$ 3.10
t/χ^2		0.42	0.36	0.88	0.18
P		0.67 > 0.05	0.55 > 0.05	0.77 > 0.05	0.85 > 0.05

Surgical technique:

All surgeries are performed by an experienced orthopedic surgeon at the same medical center. All patients undergo UKA surgery under general anesthesia, using a medial parapatellar approach. Fixed-platform cemented prostheses are uniformly employed during the surgery, along with the use of a pneumatic tourniquet. The MAKO robotic group undergoes surgery with the assistance of the MAKO robotic system based on preoperative planning(Figure1), while the conventional group undergoes surgery using conventional UKA techniques. Postoperatively, both groups of patients receive anti-inflammatory, analgesic, thrombosis prevention, and ice application for swelling.

Observation indicators:

All patients had full-length weight-bearing X-rays of both lower limbs taken by the same experienced radiologist preoperatively and on the first day postoperatively. The preoperative and postoperative lower limb mechanical axis (Hip-knee-ankle, HKA) angles were measured by the same orthopedic surgeon, and the correction angle was calculated. The HKA angle is the angle between the mechanical axis of the femur and the mechanical axis of the tibia (Fig. 2). Correction angle was defined as the difference between postoperative and preoperative HKA angles. Between-group comparisons were made for preoperative and postoperative HKA angles and correction angles, while within-group comparisons were made for preoperative and postoperative HKA angles.

Data analyses

The data analysis was conducted using SPSS 25.0 software. The measurement data such as preoperative and postoperative HKA angles and correction angles all conformed to a normal distribution and were expressed as mean $\pm$ standard deviation. Between-group comparisons were performed using independent sample *t*-tests, while within-group comparisons were conducted using paired *t*-tests. Count data were expressed as frequencies, and between-group comparisons were made using the *Chi*-square test, with a significance level set at $\alpha = 0.05$ (two-tailed).

Results

According to the results in Table 2, the average postoperative HKA for the MAKO robot group was $176.03^\circ \pm 3.08^\circ$, with an average correction of $5.13^\circ \pm 2.75^\circ$, compared to the preoperative angle of $170.09^\circ \pm 3.74^\circ$. This difference was statistically significant ($t = 12.90$, $P < 0.05$). For the conventional group, the average postoperative HKA was $175.47^\circ \pm 2.40^\circ$, with an average correction of $5.47^\circ \pm 2.21^\circ$ compared to the preoperative angle of $170.00^\circ \pm 2.95^\circ$. This difference was also statistically significant ($t = 11.62$, $P < 0.05$). However, there was no statistically significant difference in the postoperative HKA and correction angles between the two groups ($t = 0.76$, $P > 0.05$; $t = 0.51$, $P > 0.05$).

Table 2

Comparison of preoperative and postoperative HKA angles and correction degrees in two patient groups ($\bar{x} \pm s, ^\circ$)

Group	n	Preoperative HKA	Postoperative HKA	<i>t</i>	<i>P</i>	Correction degrees
MAKO robotic group	48	170.90 ± 3.74	176.03 ± 3.08	12.90	< 0.01	5.13 ± 2.75
Conventional group	22	170.00 ± 2.95	175.47 ± 2.40	11.62	< 0.01	5.47 ± 2.21
<i>t</i>		0.99	0.76			-0.51
<i>P</i>		1.19>0.05	0.45>0.05			0.61>0.05

Discussion

The MAKO robot-assisted UKA involves the creation of a patient-specific computer-assisted design model based on the preoperative CT scan. Surgeons can then use this model to plan the optimal positioning of the prosthesis and bone resection during the surgery. During the procedure, the surgeon can execute the preoperative plan with high precision using the “haptic” feedback system of the robotic arm. The system can dynamically capture the relative positions of the femur and tibia, allowing for minor adjustments to bone resection and prosthesis positioning based on the tension of ligaments at various angles of knee flexion and extension, as well as the trajectory of knee joint movement, thereby achieving the best surgical outcome [21–23]. Research has demonstrated that MAKO robotic-assisted surgery,

compared to conventional methods, can achieve more precise implant alignment in multiple planes, particularly in the accurate implantation of the femoral and tibial components, resulting in favorable clinical outcomes [12, 13, 24–27]. However, there is limited research comparing the corrective effects of the two methods on the lower limb alignment of patients.

The results of this study indicate that both MAKO robotic-assisted and conventional fixed-platform UKA are effective in correcting patients' lower limb alignment. In individuals experiencing isolated medial compartment osteoarthritis of the knee joint, the primary cause of knee joint varus deformity is intra-articular irregularity[28]. Intra-articular irregularity denotes the malformation stemming from the difference in height between the medial and lateral joint spaces. In these patients, the narrowing of the medial compartment joint space, attributed to damage and degeneration of the medial compartment joint, results in an inward angulation of the joint line in comparison to the lateral compartment. Consequently, this leads to varus alignment of the lower limb. Moreover, UKA can effectively correct the varus alignment of the lower limb by restoring the height of the medial compartment joint and improving joint congruency[28, 29].

However, it has not been conclusively proven that MAKO robotic assistance achieves better lower limb alignment correction in this study. Several factors are considered in this study: On the one hand, UKA surgery is not aimed at correcting the alignment to a neutral mechanical axis, but rather at restoring it to the pre-arthritic alignment [30, 31]. Previous research has shown that patients who have their pre-arthritic alignment restored during UKA surgery achieve better function and long-term prosthesis survival postoperatively [32–34]. Additionally, to avoid adverse outcomes related to the progression of contralateral compartment arthritis due to excessive postoperative lower limb alignment correction, most surgeons tend to maintain the postoperative alignment in a mild varus position to achieve better clinical outcomes[7]. Therefore, the degree of lower limb alignment correction with UKA surgery has certain limitations, making it difficult to demonstrate a difference between MAKO robotic-assisted and conventional surgeries in correcting lower limb alignment. On the other hand, compared to TKA, UKA is a technically demanding surgery with a steep learning curve. For young and less experienced surgeons, achieving precise alignment postoperatively still presents a certain level of difficulty [10, 35, 36]. In this study, all surgeries were performed by an experienced orthopedic surgeon. Previous studies by Bush et al. have shown that experienced high-volume orthopedic surgeons can achieve good implant alignment comparable to or exceeding the accuracy provided by robot-assisted surgery[37]. Similarly, for experienced orthopedic surgeons, robot-assisted UKA does not necessarily confer an absolute advantage in correcting alignment. Additionally, in this study, both the robot-assisted and conventional groups had limited patient numbers, making it difficult to observe differences in clinical data comparison. In the future, further large-sample randomized controlled trials are still needed to evaluate the advantages of MAKO robot assistance in correcting alignment in UKA.

Although this study did not confirm a significant advantage of the MAKO robot for experienced surgeons in correcting lower limb alignment, the results indicate its effectiveness in correcting lower limb alignment in patients. In the case of conventional surgery, UKA requires a higher level of surgical skill,

and young surgeons need to undergo a certain learning curve before achieving a certain level of accuracy in surgery[10]. However, Kayani et al.'s study indicates that robot-assisted UKA does not have a learning curve in aspects such as implant positioning and lower limb alignment correction, meaning that prior accumulated robotic experience does not affect the accuracy of implant positioning and lower limb alignment correction during surgery. Therefore, the application of MAKO robot-assisted UKA may potentially compensate for the shorter learning curve and lower surgical volume of young surgeons, minimizing the adverse outcomes of lower limb alignment correction due to their experience and technical skills. However, further research is still needed to confirm this.

The study has several limitations :(1)It is a retrospective study with a relatively limited sample size, so data analysis has limitations. Future confirmation will require large-sample randomized controlled trials. (2)The study only compared the lower limb alignment correction after fixed-bearing UKA and did not consider mobile-bearing implant surgery. Due to the different designs of the two types of implants, the surgical correction ability for lower limb alignment also differs[38]. Therefore, these results may not be applicable to mobile-bearing UKA surgery. (3)The current study only analyzed the postoperative lower limb alignment in the two patient groups and did not compare them functionally. Although previous research has shown that MAKO robot-assisted UKA can achieve better clinical function[39], there is still a lack of sufficient research to confirm the connection between postoperative lower limb alignment and clinical functional outcomes in both groups.

Conclusions

The use of MAKO robot-assisted UKA and conventional UKA both effectively correct postoperative lower limb alignment in patients. However, compared to conventional surgery, MAKO robot-assisted UKA did not demonstrate a significant advantage in lower limb alignment correction ability.

Declarations

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Conflict of Interest

On behalf of all authors, the corresponding author states that there is no conflict of interest.

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All authors have contributed sufficiently to the project to be included in the author byline, have approved the manuscript, and have agreed with its submission to the *Journal of Orthopaedic Surgery and Research*.

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Figures

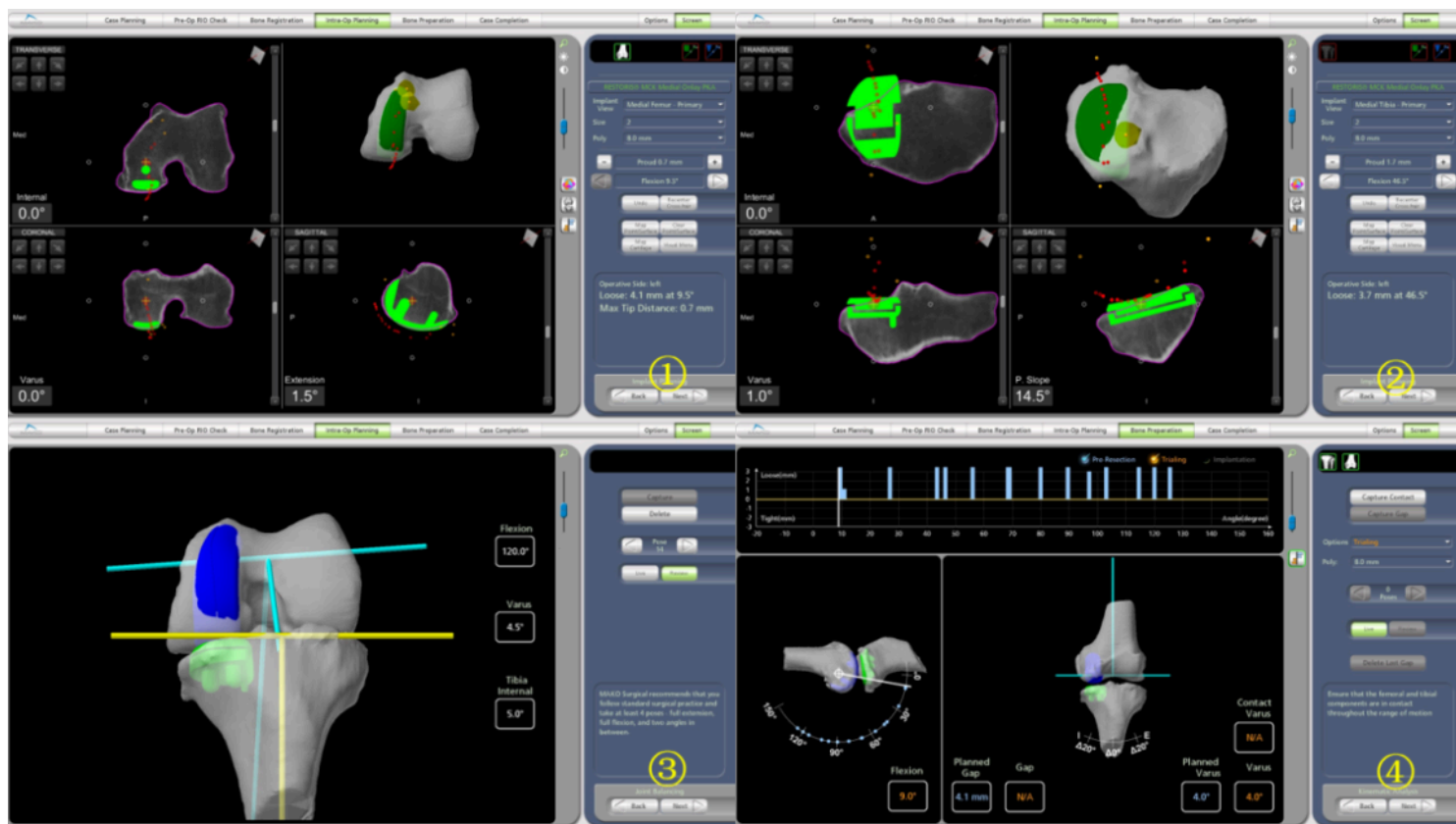


Figure 1

The preoperative planning with the MAKO robot: Preoperative planning for the femoral component Preoperative planning for the tibial component Joint balancing Kinematic analysis

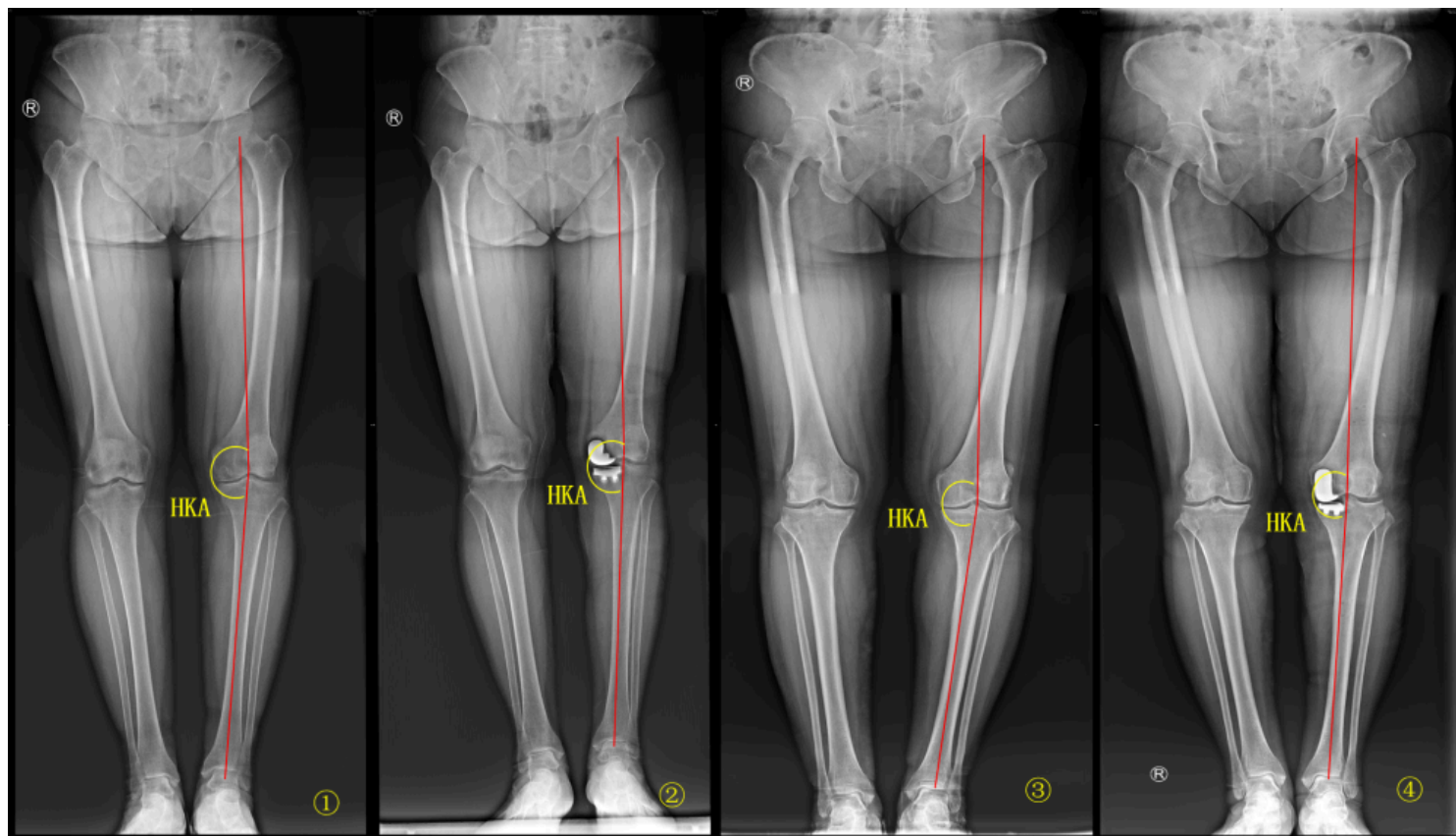


Figure 2

☐Preoperative X-rays for the conventional group
 ☐Postoperative X-rays for the conventional group
 ☐Preoperative X-rays for the MAKO robotic group
 ☐Postoperative X-rays for the MAKO robotic group