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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

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Aims

The objective of this study was to compare early postoperative functional outcomes and time to hospital discharge between conventional jig-based total knee arthroplasty (TKA) and robotic-arm assisted TKA.

Patients and Methods

This prospective cohort study included 40 consecutive patients undergoing conventional jig-based TKA followed by 40 consecutive patients receiving robotic-arm assisted TKA. All surgical procedures were performed by a single surgeon using the medial parapatellar approach with identical implant designs and standardized postoperative inpatient rehabilitation. Inpatient functional outcomes and time to hospital discharge were collected in all study patients.

Results

There were no systematic differences in baseline characteristics between the conventional jig-based TKA and robotic-arm assisted TKA treatment groups with respect to age (p = 0.32), gender (p = 0.50), body mass index (p = 0.17), American Society of Anesthesiologists score (p = 0.88), and preoperative haemoglobin level (p = 0.82). Robotic-arm assisted TKA was associated with reduced postoperative pain (p < 0.001), decreased analgesia requirements (p < 0.001), decreased reduction in postoperative haemoglobin levels (p < 0.001), shorter time to straight leg raise (p < 0.001), decreased number of physiotherapy sessions (p < 0.001) and improved maximum knee flexion at discharge (p < 0.001) compared with conventional jig-based TKA. Median time to hospital discharge in robotic-arm assisted TKA was 77 hours (interquartile range (IQR) 74 to 81) compared with 105 hours (IQR 98 to 126) in conventional jig-based TKA (p < 0.001).

Conclusion

Robotic-arm assisted TKA was associated with decreased pain, improved early functional recovery and reduced time to hospital discharge compared with conventional jig-based TKA.

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Total knee arthroplasty (TKA) is an established and highly effective procedure that is performed in over 90 000 patients per year within the United Kingdom.[1] The demand for TKA has grown rapidly over the last two decades during which time the overall costs have risen.[2] To control this expenditure optimization of postoperative recovery and reducing length of hospital stay, whilst preserving the quality of care, is required. Developments in minimally invasive surgery, pain management, anaesthesia, deep vein thrombosis prophylaxis, antibiotic prophylaxis, implant design and manufacturing and enhanced rehabilitation techniques, have all ultimately focussed on optimizing postoperative recovery and duration of inpatient stay following TKA.[2,3] Robotic-arm assisted technology has been used to enhance inpatient recovery and expedite discharge in gastrointestinal, urological, gynaecological surgery, and over the last decade in arthroplasty surgery.[3]

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Robotic-arm assisted TKA uses preoperative imaging to create a 3D reconstruction of the patient's native knee anatomy. This patient-specific model is then used to calculate a haptic window for bone resection, and select optimal implant sizing and positioning for the desired postoperative bone coverage and limb alignment.[4-6] An interactive robotic-arm with visual, audio and tactile resistive feedback then guides intraoperative bone resection within this predefined haptic window. Saw blade action outside of this stereotactic window is limited, which conceptually helps to preserve native bone stock and minimize periarticular soft-tissue injury.[7] Dynamic referencing is used to assess intra-operative flexion and extension gaps, joint stability, range of movement and limb alignment, enabling the surgeon to perform on-table modifications to bone resection, soft-tissue releases and implant positioning. Studies have shown that robotic-arm assisted TKA is associated with improved accuracy of implant positioning and reduced outliers compared with conventional jig-based TKA[7-9] but to our knowledge, there are no existing studies exploring how this translates into differences in early postoperative recovery and hospital discharge.

The objective of this prospective cohort study was to determine differences in early postoperative recovery and time to hospital discharge between patients undergoing conventional jig-based TKA versus robotic-arm assisted TKA. The primary outcome measure in this study was pain score on the numerical rating scale at 24 hours following surgery. The hypothesis was that no difference exists between the two groups relating to pain scores at 24 hours as all operative procedures were performed through the same surgical approach with a standardized rehabilitation programme.

Patients and Methods

Patient selection. This study included 80 patients with symptomatic knee osteoarthritis undergoing primary TKA at the same treatment centre between January 2016 and September 2017. This included 40 consecutive robotic-arm assisted TKAs and the preceding 40 consecutive conventional jig-based TKAs. All operative procedures were performed by the senior author (FSH) who was experienced in performing conventional jig-based and computer-navigated TKA, and had undergone cadaveric training on robotic-arm assisted TKA. The robotic group was the first cohort of patients undergoing robotic-arm assisted TKA under the operating surgeon. Inclusion criteria for this study included the following: patients with knee osteoarthritis undergoing primary TKA; patient between 18 and 80 years of age; surgery using the conventional jig-based or robotic-arm assisted technique; surgery performed by the senior author (FSH). Exclusion criteria included the following: conversion of unicompartmental to TKA; prior infection of knee joint; arthroplasty for fracture or previous osteotomy; underlying neurological dysfunction compromising mobility; and/or the use of other surgical techniques such as computer navigation for TKA. The study was assessed by the hospital review board who advised that further institutional review board assessment for ethical approval was not required. Patients were allocated to their treatment group based on the date of their surgery relative to installation of the robotic device into our institution (Princess Grace Hospital, London, United Kingdom) in September 2016. Conventional jig-based techniques were used prior to installation of the robotic device, and robotic-arm assisted surgery performed after installation.

Surgical technique. All patients received general anaesthesia with a standardized regimen of fentanyl, morphine, clonidine, paracetamol and diclofenac at induction by the same consultant anaesthetist. In conventional jig-based TKA, the patient was positioned supine on the operating table with a lateral thigh support and foot bolster to enable flexion and extension of the knee joint. In robotic-guided TKA, the patient was positioned supine with the proximal tibia and foot of the operated limb in the mobile leg holder boot. As per the surgeon's routine practice, a pneumatic tourniquet was applied but not inflated unless there was intraoperative difficulty in achieving haemostasis or compromise to the bone-cement interface. All study patients received one gram of intravenous tranexamic acid on induction and diathermy was used to help control intraoperative bleeding in all operative procedures. A conventional medial parapatellar approach was used in all patients. In both treatment groups, the objective was to achieve neutral mechanical alignment.

In conventional jig-based TKA, extramedullary referencing was used to perform tibial bone resection perpendicular to the mechanical axis of the tibia in the coronal plane with the aim of matching anatomical anteroposterior slope in the sagittal plane. The femur was prepared using an intramedullary alignment jig with the distal cutting block positioned so that the distal femoral cut was at 5° to 7° valgus angle depending on the pre-existing deformity. The distal femoral cutting block was positioned in 3° or greater of external rotation using the transepicondylar axis. Appropriate soft tissue releases were performed to ensure symmetrical and balanced flexion and extension gaps. In robotic-arm assisted TKA, the patient-specific computer aided design model of the patient's knee joint was used to create a virtual plan for optimal bone resection and implant positioning. The RIO robotic interactive orthopaedic arm system (Mako Surgical Corporation, Kalamazoo, Michigan) was then used to execute this plan intraoperatively and achieve the planned bone coverage and limb alignment. Femoral registration pins were placed through the midline incision whilst tibial registration pins were placed through a separate 3 cm longitudinal incision over the proximal anteromedial tibia. Intraoperative dynamic tracking markers were used to assess alignment, flexion and extension gaps, and range of movement, enabling on-table modifications to bone resection and implant positioning. Tibial and femoral osteotomies in the coronal plane were performed perpendicular to the tibial and femoral mechanical axes respectively to achieve neutral overall alignment. In the sagittal plane, 0° to 5° of femoral component flexion were used to optimize implant sizing whilst preventing notching. The tibial slope was initially set to 0° and then adjusted as required based on intraoperative assessment of the flexion gap and range of movement.

The cemented Triathlon Posterior Stabilized (PS) implant (Stryker, Mahwah, New Jersey), knee system with an asymmetrical patellar resurfacing button was used in both treatment groups. Polyethylene thickness was selected to maximize range of movement whilst avoiding hyperextension and ligament laxity. Patients in both treatment groups received 40 ml of 0.25% bupivacaine into the joint capsule prior to wound closure.

Postoperative inpatient care. All patients received postoperative patient-controlled analgesia (PCA) with the background intravenous morphine infusion rate set at 0.5 mg/hour, a bolus dose of 2 mg and lockout period of ten minutes. If the patient required additional analgesia then the nursing staff administered oral paracetamol and ibuprofen over this time. The PCA was stopped 24 hours postoperatively and converted to an oral regimen of regular paracetamol, ibuprofen and dihydrocodeine, with oral morphine available for breakthrough pain. All TKAs were performed at the same time of day and the first physiotherapy session was undertaken at six hours postoperatively. Patients underwent a standardized postoperative rehabilitation programme with full weight-bearing and active range of movement exercises commenced from day of surgery. Each physiotherapy session lasted 25 minutes in total and all rehabilitation was performed by the same team in both treatment groups. Patients were discharged home after adequate pain control, knee flexion to a minimum of 90°, independent mobilization with the use of crutches and independent ascent and descent of stairs.

Outcomes. All demographic data and patient outcomes were prospectively collected by two independent fellowship trained surgeons (JRTP and SK). Baseline measurements included the following: age at time of surgery (years); gender (male/female); body mass index (kg/m^2); American Society of Anesthesiologists (ASA) grade (I to IV);[10] side of intervention (right/left); and preoperative haemoglobin concentration (g/l). Findings were compared to establish any baseline differences between the two treatment groups. The following postoperative outcomes were also prospectively collected in all study patients: operating time (minutes); assessment of the intraoperative blood loss based on the difference in pre- and postoperative haemoglobin concentration (g/l); postoperative pain score on the numerical rating scale (0 to 10) at days 0 to 3; opiate analgesia (mg) requirements at days 0 to 3; range of movement at discharge (°); time from completion of operation to independent straight leg raise in the supine position (hours); number of inpatient physiotherapy sessions; use of inpatient continuous passive motion machine; time to hospital discharge (hours); and complications for 30 days following surgery. Study outcomes were selected based on previous studies showing that these early functional parameters influence time to hospital discharge and mid- to long-term clinical outcomes following TKA.[11-14]

Statistical analysis. A sample size calculation was made based on a published mean postoperative score on the numerical rating scale following TKA of 4.19 (standard deviation (SD) 1.37),[15] and a minimum clinically important difference in the numerical rating scale of one point. To achieve a minimum power of 80% in detecting this difference using a two-sample *t*-test at the level of 5% significance, the study needed to recruit a minimum of 72 patients. The assumption of a 10% drop-out rate within the 30 days follow-up period resulted in a net sample size of 80 patients (40 patients in each group). When comparing baseline and outcome measures between the two treatment groups, continuous variables with normal distributions were compared using the unpaired *t*-test, whilst the Mann–Whitney U test was used to compare continuous variables that were not normally distributed. One categorical outcome (use of continuous passive motion machine) was analysed using Fisher's exact test, due to the small number of occurrences of this outcome. Continuous variables found to be normally distributed were displayed with the mean and range, whilst the median and interquartile range (IQR) were presented for factors not found to follow a normal distribution. Categorical variables were shown by the number and percentage of patients where the outcome occurred. Statistical significance was set at a p-value < 0.05 for all analyses and all statistical analysis was performed using SPSS software version 12 (SPSS Inc., Chicago, Illinois).

Results

There was no statistical difference in relation to baseline characteristics recorded between conventional jig-based TKA and robotic-arm assisted TKA (Table I). Interclass correlation coefficient was above 0.8 (0.88 to 0.92) for all postoperative outcomes recorded suggesting good interobserver agreement between the two independent observers. Study outcomes are displayed in Table II.

Patients undergoing robotic-arm assisted surgery had reduced pain scores at each of the four time intervals following surgery compared with conventional jig-based surgery (p < 0.001, unpaired *t*-test). In both groups, pain scores were greatest at day one, which reflected the day that the PCA was converted to oral analgesia (Fig. 1). Opiate analgesia requirements were also reduced in the robotic-group compared with the conventional group and this was found to be statistically significant at all four time points (p < 0.001, Mann-Whitney U test) (Fig. 2). There was no significant difference in preoperative haemoglobin concentration between the two treatment groups but patients undergoing conventional TKA had a greater reduction postoperatively compared with those undergoing robotic-arm assisted TKA (p < 0.001, unpaired *t*-test). The pneumatic tourniquet was not inflated in any study patient. Two patients in the robotic-arm assisted TKA group each received two units of red blood cells compared with four patients (10%) in the conventional jig-based TKA group. Attainment of physiotherapy targets including time to straight leg raise (p < 0.001, Mann-Whitney U test) and maximum knee flexion at discharge (p < 0.001, unpaired *t*-test) followed the same trend with improved outcomes in the robotic-arm assisted TKA group compared with the conventional jig-based TKA group (Figs 3 to 6). Each boxplot graphically displays the respective study outcome with the transverse line showing the median value and the box part representing the interquartile range. The whiskers extend to the minimum and maximum value, except for values more than 1.5 × interquartile range width from the lower or upper quartiles, which are plotted separately. There was a tendency towards to increased operating time in robotic-arm assisted TKA but overall hospital discharge was reduced in the robotic group (p < 0.001).

There were two inpatient complications in this study, which included one patient from each treatment group. In the conventional jig-based TKA, one patient had minor wound dehiscence from the distal part of the midline incision, which was treated

Table I. Demographic and baseline measurements for study patients undergoing conventional jig-based total knee arthroplasty (TKA) and robotic-arm assisted TKA

Characteristic	Category	Conventional (n = 40)	Robotic (n = 40)	p-value
Mean age (yrs)	-	71.4 (54.2 to 87.1)	69.7 (53.1 to 85.3)	0.32*
Gender (%)	Female	25 (*62*)	22 (*55*)	0.50†
	Male	15 (*38*)	18 (*45*)	
Mean BMI (kg/m^2)	-	26.7 (20.3 to 36.0)	27.9 (21.8 to 37.1)	0.17*
ASA score (%)	I	7 (*18*)	8 (*20*)	0.88†
	II	29 (*72*)	27 (*67*)	
	III	4 (*10*)	5 (*13*)	
Side intervention (%)	Left	20 (*50*)	18 (*45*)	0.65†
	Right	20 (*50*)	22 (*55*)	
Mean preoperative Hb (g/L)	-	132.7 (95.1 to 164.3)	133.3 (113.2 to 154.6)	0.82*

*Unpaired *t*-test
†Chi-squared test
BMI, body mass index; ASA, American Society of Anesthesiologists; Hb, Haemoglobin

Table II. Study outcomes for patients undergoing conventional jig-based total knee arthroplasty (TKA) and robotic-arm assisted TKA

Outcome	Conventional (n = 40)	Robotic (n = 40)	p-value
Mean operating time (mins)	61.2 (54.6 to 83.1)	70.4 (59.2 to 91.7)	0.34*
Mean fall in Hb (g/L)	26.1 (5.1 to 49.6)	18.7 (8.0 to 37.2)	< 0.001*
Mean postoperative Hb (g/L)	106.7 (77.3 to 138.4)	114.7 (86.4 to 139.1)	0.01*
Mean pain score (NRS) – Day 0	5.4 (3.0 to 7.0)	3.1 (2.0 to 5.0)	< 0.001*
Mean pain score (NRS) – Day 1	6.3 (4.0 to 8.0)	3.6 (2.0 to 6.0)	< 0.001*
Mean pain score (NRS) – Day 2	6.1 (3.0 to 8.0)	3.3 (1.0 to 5.0)	< 0.001*
Mean pain score (NRS) – Day 3	4.5 (2.0 to 7.0)	2.6 (1.0 to 5.0)	< 0.001*
Median analgesia (mg) – Day 0	36.0 (IQR 29.0 to 51.3)	20.0 (IQR 16.0 to 28.5)	< 0.001†
Median analgesia (mg) – Day 1	10.0 (IQR 10.0 to 20.0)	10.0 (IQR 0.0 to 10.0)	< 0.001†
Median analgesia (mg) – Day 2	10.0 (IQR 10.0 to 20.0)	10.0 (IQR 0.0 to 10.0)	< 0.001†
Median analgesia (mg) – Day 3	10.0 (IQR 0.0 to 10.0)	0.0 (IQR 0.0 to 5.0)	< 0.001†
Median time to SLR (hrs)	31.0 (IQR 24.0 to 44.0)	20.0 (IQR 18.0 to 21.0)	< 0.001†
Median knee extension (°)	0.0 (IQR 0.0 to 0.0)	0.0 (IQR 0.0 to 0.0)	0.08†
Mean knee flexion (°)	93.3 (90.0 to 110.0)	104.1 (90.0 to 120.0)	< 0.001*
Median physiotherapy sessions (n)	11.0 (IQR 9.0 to 11.0)	5.0 (IQR 5.0 to 6.0)	< 0.001†
CPM sessions, n (%)	5 (*12.5*)	2 (*5.0*)	0.43‡
Median time to discharge (hrs)	105.0 (IQR 98.0 to 126.0)	77.0 (IQR 74.0 to 81.0)	< 0.001†

*Unpaired *t*-test
†Mann-Whitney U test
‡Fisher's exact test
NRS, numerical rating scale; Hb, haemoglobin concentration; IQR, interquartile range; SLR, straight leg raise; CPM, continuous passive motion machine

with prophylactic antibiotics and adhesive skin strips to approximate the wound edges. In the robotic-arm assisted TKA group, one patient had minor wound dehiscence over the incision for the proximal tibial registration pins. This was treated with regular dressings and prophylactic oral antibiotics. Both patients made a satisfactory recovery with no further complications.

Discussion

In this prospective cohort study, there were no systematic differences in baseline characteristics between the two treatment groups, surgery was undertaken by a single surgeon using the same approach with identical implant designs, and inpatient rehabilitation performed using a standardized programme with the same rehabilitation team. Robotic-arm assisted TKA was associated with reduced postoperative pain, decreased analgesia requirements, smaller drop in haemoglobin concentration, shorter time to be able to perform a straight leg raise, improved maximum knee flexion at discharge and decreased length of stay compared with conventional jig-based TKA. Our findings suggest that implementation of robotic-arm assisted surgery may help to further improve early functional recovery and reduce time to hospital discharge in patients undergoing TKA.

Analysis of data from the National Joint Registry of England and Wales showed that persistent pain following TKA is the strongest predictor of patient dissatisfaction and reduced functional outcomes including the Oxford Hip Score.[16] Regression analysis has also shown that postoperative pain is the most important prognostic indicator for long-term dissatisfaction following TKA.[11] Our study showed reduced pain and opiate analgesia requirements at each of the four time points in patients undergoing

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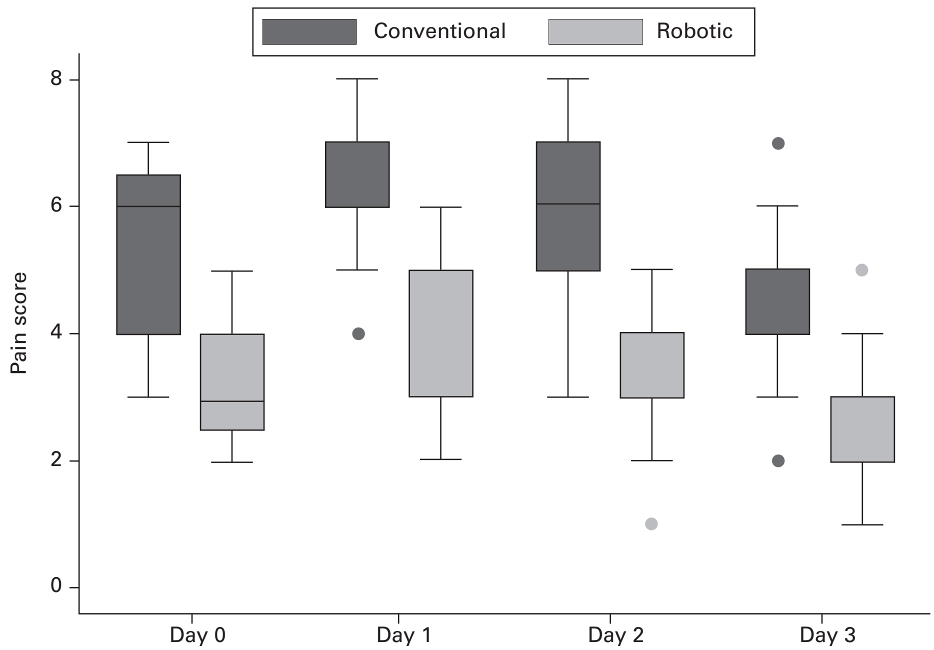

Fig. 1

Boxplot showing pain score as measured using the numerical rating scale in conventional jig-based total knee arthroplasty (TKA) *versus* robotic-arm assisted TKA.

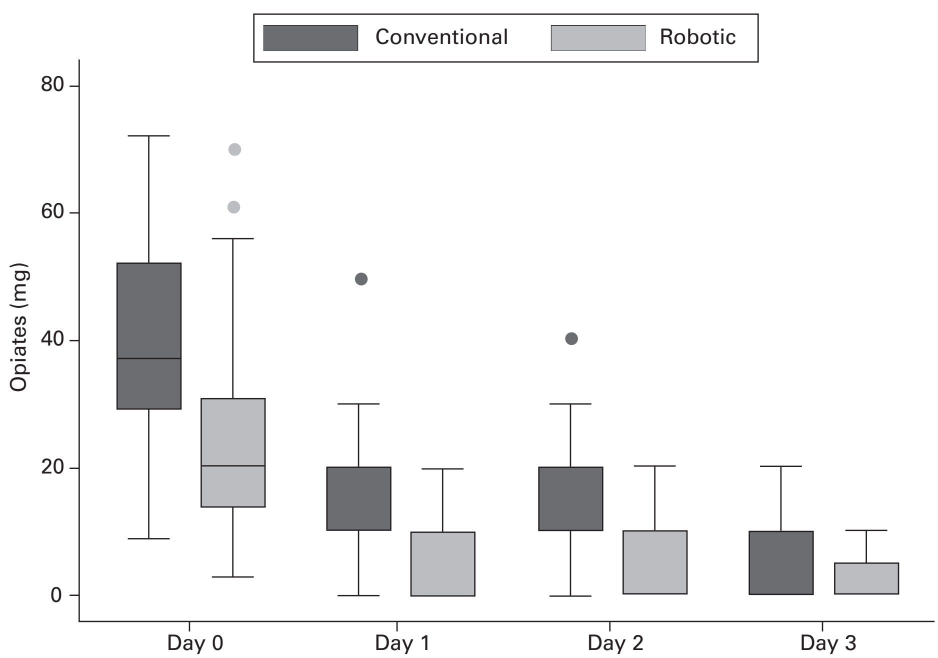

Fig. 2

Boxplot showing opiate analgesia requirements in conventional jig-based total knee arthroplasty (TKA) *versus* robotic-arm assisted TKA.

robotic-arm assisted surgery compared with conventional jig-based TKA, which we hope would lead to improved long-term patient satisfaction and functional outcomes in the robotic TKA group. Marchand et al[17] compared outcomes in 28 robotic-arm assisted TKAs matched with 20 conventional jig-based TKAs and showed that pain, physical function scores and patient satisfaction measured using Western Ontario and McMaster Universities Arthritis Index[18] were better in the robotic group compared with the conventional group at six months after surgery. Our data shows important differences in pain and analgesia requirements in the early postoperative period but the long-term clinical significance of these remains unknown. The present data will be subsequently correlated to validated long-term clinical and functional outcome measures.

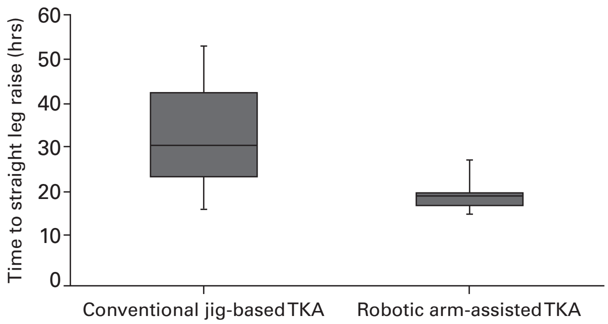

Fig. 3

Boxplot showing time to be able to perform a straight leg raise (hours) in conventional jig-based total knee arthroplasty (TKA) *versus* robotic-arm assisted TKA.

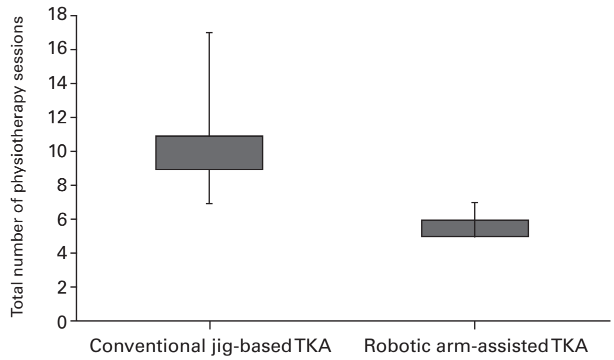

Fig. 5

Boxplot showing number of inpatient physiotherapy sessions in conventional jig-based total knee arthroplasty (TKA) *versus* robotic-arm assisted TKA.

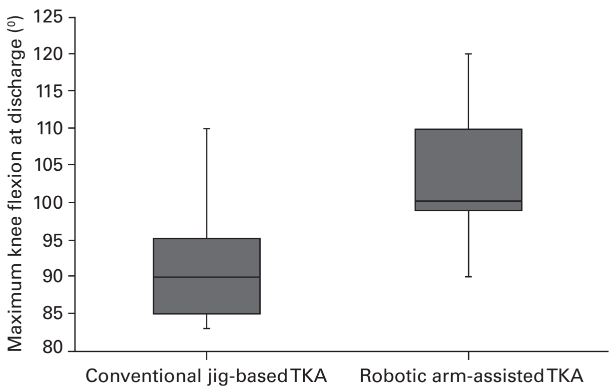

Fig. 4

Boxplot showing maximum knee flexion (°) at discharge in conventional jig-based total knee arthroplasty (TKA) *versus* robotic-arm assisted TKA.

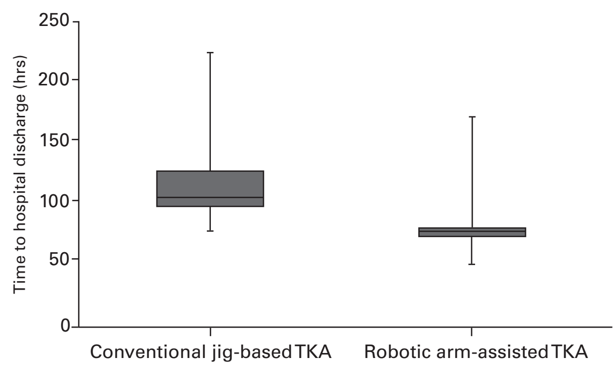

Fig. 6

Boxplot showing time to hospital discharge (hours) in conventional jig-based total knee arthroplasty (TKA) *versus* robotic-arm assisted TKA.

Robotic-arm assisted TKA uses dynamic referencing to assess intraoperative knee stability, alignment and range of movement, enabling on-table adjustments to bone resection and implant positioning to be performed. The surgeon is able manipulate bone cuts to achieve the desired flexion and extension gaps without having to perform extensive soft-tissue releases. No additional soft-tissue releases for knee balancing were performed in the robotic-arm assisted group in this study. Reduced soft-tissue dissection and muscle trauma may have helped to reduce the local inflammatory response and time to attainment of physiotherapy targets such as straight leg raise in the robotic-group compared with patients undergoing conventional jig-based TKA. Siebert et al[19] conducted a retrospective study on 70 patients undergoing robotic-arm assisted TKA *versus* a matched historic cohort of 50 conventional TKAs, and observed reduced postoperative soft-tissue swelling in the robotic-group but the size or difference in the effect was not quantified. There are no existing studies comparing the local or systemic inflammatory responses in conventional *versus* robotic arm assisted surgery but existing studies comparing conventional *versus* minimally invasive surgical approaches for hip and knee arthroplasty have shown that the extent of soft-tissue release was associated with the magnitude of the inflammatory cytokine response and signal changes visible on postoperative MRI.[20,21]

The technical objectives of TKA are to restore mechanical alignment, preserve the joint line, balance flexion and extension gaps and maintain the normal Q angle for correct patella tracking. In order to achieve these objectives, preservation of the surrounding soft-tissue envelope is essential.[22,23] Compromise to the periarticular soft-tissue structures such as the collateral ligaments, posterior cruciate ligament or extensor mechanism, may compromise postoperative clinical and functional recovery, reduce stability and decrease implant survivorship.[22-24] Manual based techniques may lead to inadvertent disruption of the periarticular soft-tissue structures,[24] and in many cases these ligamentous and soft-tissue injuries are underreported.[25] Robotic-arm assisted TKA limits saw blade action to within the fixed stereotactic field, which conceptually helps to reduce iatrogenic bone and soft-tissue injury.[26] In this study, no intraoperative macroscopic soft-tissue complications were identified but previous cadaveric reports have shown that robotic-arm assisted technology can reduce more discrete periarticular soft-tissue injuries. Khlopas et al[26] conducted a prospective non-randomized study comparing soft-tissue injury in six cadaveric knees undergoing robotic-arm assisted TKA *versus* seven conventional jig-based TKA. The authors found mild posterior cruciate ligament injury in two of the seven conventional jig-based TKAs compared with none of the six robotic-arm assisted TKAs, with more extensive soft-tissue disruption in the conventional group on careful visual evaluation and palpation. In the current study, improved preservation of the periarticular soft-tissue envelope and reduced iatrogenic trauma in the robotic-arm assisted group may have helped to limit pain and enhance early functional recovery.

In this study, there was a trend towards increased operating time in the robotic group but this was not statistically significant. Our findings are consistent with a previous study by Song et al,[7] who conducted a prospective study on 30 patients undergoing sequential TKA, which included conventional jig-based TKA on one side followed by robotic-arm assisted TKA on the contralateral side. The authors reported no difference in operating time between the two treatment groups, with mean operating time in the robotic-arm assisted of 95 minutes (SD 18). Park and Lee[27] reported on the learning curve of robotic-arm assisted TKA and showed that six of their 32 robotic-arm assisted TKAs had short-term complications, including superficial infection, patellar ligament rupture, patellar dislocation, supracondylar fracture, patellar fracture and common peroneal injury during the learning phase. The reduced operating time and absence of intraoperative complications in our cohort of patients compared with these previous studies may be due to the operating surgeon in this study having extensive training in robotic-arm assisted TKA in cadaver-workshops and prior experience in performing computer navigated arthroplasty. As such progression along the learning curve for some aspects of robotic-assisted surgery may have already been achieved.

There is growing literature showing that robotic-arm assisted knee arthroplasty is associated with improved accuracy of implant positioning, better short- to mid-term functional scores and reduced revision rates compared with conventional jig-based TKA.[4,5,7,8,28-30] Although a financial analysis has not been undertaken, our findings do show important differences in inpatient rehabilitation and hospital stay, which will aid healthcare policy makers in the allocation of medical resources and cost planning for the implementation of this technology into clinical practice.

There are several limitations of this study that need to be considered when interpreting the findings. First, all patients received general anaesthetic, which is not keeping in with current trends in enhanced recovery programmes[31] and this may have reduced the overall rehabilitation time in both treatment groups. Second, the reported early functional outcome measures were not correlated to long-term clinical outcomes or implant survivorship. Third, patients and observers recording outcomes of interest could not be blinded as patients in the robotic group had an additional incision over the proximal tibia for the insertion of the registration pins. Fourth, the use of historical controls may have introduced bias into the study due to increasing drive for faster rehabilitation and reduced length of stay. Improved outcomes in the robotic group may therefore not be exclusively due to surgical technique. Fifth, preoperative grading of the arthritis and radiological outcomes were not analysed in this study. Despite these limitations, this prospective single surgeon study used the same surgical approach, implant design and rehabilitation programme in two systemically matched treatment groups, and showed improved early functional recovery and time to hospital discharge with no additional risk of complications in robotic-arm assisted TKA compared with conventional jig-based TKA.

Robotic-arm assisted TKA was associated with reduced postoperative pain, decreased analgesia requirements, less reduction in postoperative haemoglobin levels, shorter time to perform a straight leg raise, decreased length of stay, and improved maximum knee flexion at discharge compared with conventional jig-based TKA. There was no additional risk of inpatient complications in patients undergoing robotic-arm assisted TKA compared with conventional jig-based TKA.

Take home message:

- Robotic-arm assisted TKA is associated with reduced postoperative pain and analgesia requirements compared with conventional jig-based TKA.
- Robotic-arm assisted TKA is associated with improved early functional recovery compared with conventional jig-based TKA.
- Robotic-arm assisted TKA is associated with reduced time to hospital discharge compared with conventional jig-based TKA.

References

1. **No authors listed.** National Joint Registry for England and Wales. 9th Annual Report, 2012. http://www.njrcentre.org.uk (date last accessed 22 March 2018).
2. **El Bitar YF, Illingworth KD, Scaife S, Horberg JV, Saleh KJ.** Hospital Length of Stay following Primary Total Knee Arthroplasty: Data from the Nationwide Inpatient Sample Database. *J Arthroplasty* 2015;30:1710–1715.
3. **Gourin CG, Terris DJ.** History of Robotic Surgery. In: Faust RA, ed. *Robotics in Surgery: History, Current and Future Applications.*New York (NY): Nova Science Publishers, Inc., 2007:3-12.
4. **Cobb J, Henckel J, Gomes P, et al.** Hands-on robotic unicompartmental knee replacement: a prospective, randomised controlled study of the acrobot system. *J Bone Joint Surg [Br]* 2006;88-B:188–197.
5. **Dunbar NJ, Roche MW, Park BH, et al.** Accuracy of dynamic tactile-guided unicompartmental knee arthroplasty. *J Arthroplasty* 2012;27:803–808.
6. **Conditt MA, Roche MW.** Minimally invasive robotic-arm-guided unicompartmental knee arthroplasty. *J Bone Joint Surg [Am]* 2009;91-A(Suppl 1):63–68.
7. **Song EK, Seon JK, Park SJ, et al.** Simultaneous bilateral total knee arthroplasty with robotic and conventional techniques: a prospective, randomized study. *Knee Surg Sports Traumatol Arthrosc* 2011;19:1069–1076.
8. **Song EK, Seon JK, Yim JH, Netravali NA, Bargar WL.** Robotic-assisted TKA reduces postoperative alignment outliers and improves gap balance compared to conventional TKA. *Clin Orthop Relat Res* 2013;471:118–126.
9. **Mannan A, Vun J, Lodge C, Eyre-Brook A, Jones S.** Increased precision of coronal plane outcomes in robotic-assisted total knee arthroplasty: A systematic review and meta-analysis. *Surgeon* 2018. (Epub ahead of print) PMID: 29439922.
10. **Saklad M.** Grading of patients for surgical procedures. *Anesthesiol* 1941;2:281–284.
11. **Scott CE, Howie CR, MacDonald D, Biant LC.** Predicting dissatisfaction following total knee replacement: a prospective study of 1217 patients. *J Bone Joint Surg [Br]* 2010;92-B:1253–1258.
12. **Kerr HL, Armstrong LA, Beard L, Teichmann D, Mutimer J.** Challenges to the orthopaedic arthroplasty enhanced recovery programme. *J Perioper Pract* 2017;27:15–19.
13. **Husted H, Holm G, Jacobsen S.** Predictors of length of stay and patient satisfaction after hip and knee replacement surgery: fast-track experience in 712 patients. *Acta Orthop* 2008;79:168–173.
14. **Hossain FS, Patel S, Fernandez MA, Konan S, Haddad FS.** A performance based patient outcome score for active patients following total knee arthroplasty. *Osteoarthritis Cartilage* 2013;21:51–59.
15. **Pinto PR, McIntyre T, Ferraro R, Araújo-Soares V, Almeida A.** Persistent pain after total knee or hip arthroplasty: differential study of prevalence, nature, and impact. *J Pain Res* 2013;6:691–703.

16. **Baker PN, van der Meulen JH, Lewsey J, Gregg PJ, National Joint Registry for England and Wales.** The role of pain and function in determining patient satisfaction after total knee replacement: data from the National Joint Registry for England and Wales. *J Bone Joint Surg [Br]* 2007;89-B:893–900.
17. **Marchand RC, Sodhi N, Khlopas A, et al.** Patient Satisfaction Outcomes after Robotic Arm-Assisted Total Knee Arthroplasty: A Short-Term Evaluation. *J Knee Surg* 2017;30:849–853.
18. **Bellamy N, Buchanan WW, Goldsmith CH, Campbell J, Stitt L.** Validation study of WOMAC: a health status instrument for measuring clinically important patient-relevant outcomes following total hip or knee arthroplasty in osteoarthritis. *J Orthop Rheumatol* 1988;1:95–108.
19. **Siebert W, Mai S, Kober R, Heeckt PF.** Technique and first clinical results of robot-assisted total knee replacement. *Knee* 2002;9:173–180.
20. **Bremer AK, Kalberer F, Pfirrmann CW, Dora C.** Soft-tissue changes in hip abductor muscles and tendons after total hip replacement: comparison between the direct anterior and the transgluteal approaches. *J Bone Joint Surg [Br]* 2011;93-B:886–889.
21. **Berkin PF, Doppelt JD, Kephart CJ, et al.** Comparison of minimally invasive direct anterior versus posterior total hip arthroplasty based on inflammation and muscle damage markers. *J Bone Joint Surg [Am]* 2011;93-A:1392–1398.
22. **Griffin FM, Insall JN, Scuderi GR.** Accuracy of soft tissue balancing in total knee arthroplasty. *J Arthroplasty* 2000;15:970–973.
23. **Whiteside LA.** Soft tissue balancing: the knee. *J Arthroplasty* 2002;17(Suppl 1):23–27.
24. **Lee G- C, Lotke PA.** Management of intraoperative medial collateral ligament injury during TKA. *Clin Orthop Relat Res* 2011;469:64–68.
25. **McNabb DC, Kim RH, Springer BD.** Instability after total knee arthroplasty. *J Knee Surg* 2015;28:97–104.
26. **Khlopas A, Chughtai M, Hampp EL, et al.** Robotic-arm assisted total knee arthroplasty demonstrated soft tissue protection. *Surg Technol Int* 2017;30:441–446.
27. **Park SE, Lee CT.** Comparison of robotic-assisted and conventional manual implantation of a primary total knee arthroplasty. *J Arthroplasty* 2007;22:1054–1059.
28. **Mofidi A, Plate JF, Lu B, et al.** Assessment of accuracy of robotically assisted unicompartmental arthroplasty. *Knee Surg Sports Traumatol Arthrosc* 2014;22:1918–1925.
29. **Rodriguez F, Harris S, Jakopec M, et al.** Robotic clinical trials of uni-condylar arthroplasty. *Int J Med Robot* 2005;1:20–28.
30. **Börner M, Wiesel U, Ditzen W.** Clinical experiences with ROBODOC and the Duracon Total Knee. In: Stiehl JB, Konermann W, Haaker RG, eds. *Navigation and Robotics in Total Joint and Spine Surgery*. Berlin, Germany: Springer-Verlag, 2004:362–366.
31. **Soffin EM, YaDeau JT.** Enhanced recovery after surgery for primary hip and knee arthroplasty: a review of the evidence. *Br J Anaesth* 2016;117(suppl 3)62–72.

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