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Robotic unicompartmental knee arthroplasty

CURRENT CHALLENGES AND FUTURE PERSPECTIVES

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Keywords: Unicompartmental knee arthroplasty, Robotics, Implant position

Unicompartmental knee arthroplasty (UKA) is an established and highly effective treatment for patients with end-stage disease affecting one compartment of the knee joint.[1] The procedure accounts for between 8% and 10% of all knee arthroplasty procedures performed in the United Kingdom and United States.[2,3] There are several advantages of performing UKA over total knee arthroplasty (TKA), including reduced operating time, decreased intraoperative blood loss, reduced periarticular soft-tissue trauma, improved preservation of bone stock, better restoration of native kinematics, increased patient satisfaction, and improved functional outcomes.[4-7] However, UKA is associated with decreased implant survivorship and increased revision rates compared with TKA.[8,9] Accuracy of component positioning and limb alignment are important prognostic variables that affect implant survival and time to revision surgery following UKA.[9-11] Consequently, techniques that improve the accuracy of implant positioning and limb alignment in UKA may help to improve long-term survivorship and reduce the burden of revision disease.

Experts from a range of industries, including aviation training, military activity, financial services, and medical care, have shown that each industry moves through five distinct phases: 1) consideration of the industry as an art by specialists within the field; 2) development of specific rules and instruments; 3) creation of standardized protocols and procedures; 4) automation; and 5) integration of computer technology.[12,13] During the final phase, accurate objective real-time data provided by computerized systems help to minimize the risk of system error, improve efficiency, and optimize productivity. Within the healthcare industry, robotic technology has been implemented in general surgery, urology, cardiology, ophthalmology, and gynaecology to minimize human error, improve surgical precision, enhance postoperative rehabilitation, and improve long-term clinical outcomes.[14] Over the last decade, robotic technology has gained momentum as an avenue for improving accuracy of implant positioning and limb alignment compared with conventional jig-based techniques for UKA.[15-18]

Cobb et al[15] conducted a prospective randomized study on 27 patients with medial compartment knee osteoarthritis undergoing conventional jig-based UKA *versus* robotic UKA.[15] The authors reported that all patients undergoing robotic UKA had tibiofemoral alignment in the coronal plane within 2° of the planned position, compared with only 40% in those undergoing conventional jig-based UKA. Bell et al[17] performed a prospective randomized controlled study assessing accuracy of implant positioning using postoperative CT scans in 62 robotic UKAs *versus* 58 conventional UKAs, and found that robotic UKA reduced root mean square errors in achieving planned femoral and tibial implant positioning. Herry et al[18] retrospectively reviewed plain radiographs in 40 conventional jig-based UKAs *versus* 40 robotic UKAs, and found improved restitution of the native joint line with robotic-guided surgery. Improved accuracy of implant position with robotic UKA may help to improve long-term implant survivorship and facilitate implementation of cementless implants for future UKA implant designs.

Studies using data from three separate national joint registries have demonstrated a relationship between the surgical (or unit)

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doi: 10.1302/2046-3758.86.BJR-2019-0037

Bone Joint Res 2019;8:228–231.

case-load and revision rate following UKA.[19-21] Surgeon-controlled errors in implant positioning are the most common reason for implant failure, and low case volume has been identified as a risk factor for early revision surgery following UKA.[18,19] Liddle et al[19] reviewed outcomes of 41 986 UKAs from the National Joint Registry for England and Wales, and found that optimal outcomes (as assessed using revision rates) were achieved with UKA usage in between 40% and 60% of a surgeon's practice. Acceptable revision rates were achieved with UKA usage in 20% or more of UKA practice, while surgeons with the lowest usage (less than 5%) had the highest revision rates. However, achieving optimal UKA usage is challenging, owing to the limited number of patients with single compartment disease and strict inclusion criteria for conventional UKA.

Robotic UKA uses a preoperative CT scan (image-guided) or intraoperative osseous registration (imageless) to create a patient-specific virtual 3D reconstruction of the knee joint. The surgeon uses this virtual model to plan optimal bone coverage, implant positioning, and limb alignment for each patient's unique knee anatomy. An intraoperative robotic arm then helps to execute this plan with a high level of accuracy, and stereotactic boundaries limit bone resection to the predefined femoral and tibial haptic windows. There is no learning curve effect in robotic UKA for accuracy of achieving the planned femoral or tibial implant positioning, posterior condylar offset ratio, limb alignment, and restoration of native joint line.[16] Robotic technology offers an opportunity for low-volume UKA surgeons to achieve high levels of accuracy in implant positioning. Robotic UKA may thus help overcome the current challenges of surgeons or units/departments needing to achieve minimum UKA case volumes to minimize the risk of surgeon-induced errors in implant positioning.

Achieving proper soft-tissue tensioning and ligamentous balancing are important technical objectives for optimizing stability and long-term functional outcomes in UKA. In conventional jig-based surgery, assessment of the periarticular soft-tissue tension and limb alignment are performed manually, which is dependent on the skill and expertise of the operating surgeon. Robotic UKA uses optical motion capture technology to provide real-time medial and lateral gap measurements while applying valgus/varus strain to appropriately tension the ligaments through the arc of flexion. These patient-specific intraoperative data may be used to fine-tune implant positioning to achieve the desired ligamentous tension and limb alignment.[22] Intraoperative data on the 'tightness' and 'looseness' of the knee joint through the arc of flexion may be used to further adjust bone resection, implant sizes, and implant positions to achieve the desired knee kinematics. Further studies are required to establish if the improved ligament tensioning in robotic UKA translates to differences in knee kinematics, implant stability, and range of movement compared with conventional manual UKA.

Bone resection in robotic knee arthroplasty is restricted to the confines of the stereotactic boundaries, which may help to reduce periarticular soft-tissue injury and enhance postoperative rehabilitation compared with conventional manual knee arthroplasty. Kayani et al[23] conducted a prospective cohort study on 146 patients showing robotic UKA was associated with reduced postoperative pain, decreased opiate analgesia consumption, reduced inpatient physiotherapy, and decreased mean time to hospital discharge compared with conventional manual UKA (42.5 hours (SD 5.9) *vs* 71.1 hours (SD 14.6), respectively; $p < 0.001$). Blyth et al[24] performed a prospective randomized control trial on 139 patients and reported robotic UKA reduced median pain scores by 55.4% compared with conventional manual UKA from postoperative day one to week eight after surgery. As many arthroplasty centres move towards day case UKA, robotic UKA may help to facilitate this practice through improved pain control, enhanced functional rehabilitation, reduced need for physiotherapy, and earlier time to hospital discharge.[25]

Improved accuracy of implant positioning in robotic UKA has not been shown to improve mid-term to long-term clinical or functional outcomes compared with conventional jig-based UKA. Blyth et al[24] reported that robotic UKA was associated with improved American Knee Society Score for three months following surgery, but there was no difference in functional outcomes observed between conventional and robotic UKA at one year after surgery. Subgroup analysis of the 35 most active patients revealed robotic UKA improved Knee Society Scores, Oxford Knee Scores, and Forgotten Joint Scores compared with conventional manual UKA at two years' follow-up.[26] More recently, Canetti et al[27] reviewed outcomes in 28 highly active patients undergoing lateral compartment UKA, and found that robotic UKA enabled markedly earlier mean return to sporting activity compared with conventional UKA (4.2 months (SD 1.8) *vs* 10.5 months (SD 6.7), respectively; $p<0.01$). These studies suggest that robotic UKA enables improved short-term functional outcomes in highly active patients, although overall functional outcomes are comparable to those of conventional jig-based UKA. Many studies have shown excellent functional outcomes with both treatment techniques for UKA and therefore subgroup analysis is essential for overcoming the ceiling effect with routine patient-reported outcome measures.

Aseptic loosening and progression of osteoarthritis in the remaining native knee compartments are common reasons for failure in UKA.[3,4] Robotic technology enables accurate intraoperative assessment of limb alignment to avoid overcorrection, which may help to limit disease progression in the other compartments and improve time to revision surgery compared with conventional manual UKA. Pearle et al[28] conducted a prospective, multicentre review of 1135 robotic UKAs and found implant survivorship was 98.8% at a minimum of 22 months' follow-up, which is superior to the survival rates of conventional UKA reported in the national joint registries of the United Kingdom (95.6%), Sweden (95.3%), Australia (95.1%), and New Zealand (96.1%).[28-32] Batailler et al[33] compared outcomes in 80 conventional UKAs *versus* 80 robotic UKAs, and found revision rates in robotic UKA were 5% compared with 9% in conventional manual UKA, although this difference was not statistically significant. Importantly, 86% of revisions in the conventional group were secondary to component malposition or limb malalignment, compared with none in the robotic group.[33]

Moschetti et al[34] used a Markov decision analysis tool to compare cost-effectiveness of conventional UKA *versus* robotic UKA. Using a two-year failure rate of 1.2% for robotic UKA and 3.1% for manual UKA, the authors reported that robotic UKA was a cost-effective procedure compared with manual UKA if robotic UKA case volume exceeded 94 cases per year. However, these findings should be interpreted with caution as several additional costs with robotic technology were overlooked. Robotic UKA is also associated with substantial costs for installation of the robotic device, additional preoperative CT scanning, further training for surgical staff, and increased operative times during the initial learning phase. Many robotic devices are also only compatible with specific implants and therefore additional costs for purchasing equipment and implants must be considered in any future cost analysis. Further studies on resource use and cost-effectiveness on conventional *versus* robotic UKA are required before this technology can be implemented into mainstream UKA practice.

Overall, robotic UKA improves accuracy of implant positioning, enhances postoperative functional rehabilitation, and improves early functional outcomes in highly active individuals compared with conventional jig-based UKA. Robotic technology also provides live intraoperative data on knee kinematics through the arc of flexion that can be used to fine-tune implant positioning and optimize soft-tissue tensioning. Robotic UKA offers a unique opportunity for low-volume arthroplasty surgeons to achieve high levels of accuracy in implant positioning, which may help to improve implant survivorship and reduce the burden of revision disease. However, further studies are required to assess the effect of robotic UKA on long-term functional outcomes, implant survivorship, cost-effectiveness, and complications compared with conventional jig-based UKA.

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