Robot-assisted hip and knee replacements

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While physiotherapists will always ideally aim to treat patients with joint conditions with non-surgical modalities, the development and use of technology, and the understanding of the essential role physiotherapy plays in postoperative rehab, does offer the option for confident referral for surgical intervention when required. This article sets out the case for robot-assisted joint replacement for patients with hip and knee conditions.

LEARNING OUTCOMES
TO SUPPORT PHYSIO FIRST QAP

1. There are a variety of robot-assisted joint replacement systems available, and these must be evaluated on their own merits.
2. Robot-assisted hip and knee replacement has the potential to improve the technical approach to surgery, as well as final / long-term outcomes.
3. Early results of robot-assisted joint replacements are promising in terms of earlier recovery, and have the potential for less invasive interventions and improved satisfaction levels after surgery.
4. It is necessary for a longer-term follow-up on robot-assisted surgery to evaluate costs / benefits and the impact on clinical outcomes.

Introduction

The application and use of technology across all surgical specialties has increased significantly over the past few years. There has been a rapid uptake of robot-assisted surgery driven by the perceived advantages of the applied technology.

With regard to hip and knee surgery, all the major implant companies have developed, or are developing, robot-assisted platforms, e.g. MAKO® robot arm-assisted hip and knee replacement by Stryker (figure 1), Rosa by Zimmer-Biomet (figure 2), Velys by Depuy (figure 3) and NAVIO / CORI Surgical system by Smith & Nephew (figure 4). Some systems, such as Velys by Depuy, have not, at the time of writing, achieved CE approval for use in the UK or EU.

The term "robot" is a non-specific description of computer based systems and technologies in hip and knee replacement surgery. However, the various robotic systems in the marketplace are not similar; they can be active, semi-active and passive depending on the extent of control provided to the surgeon and the robot. Active systems complete tasks entirely independent of the surgeon. Passive systems enhance the surgeon's ability to perform certain tasks with supervision by the software and robot system.

FIGURE 1: MAKO® applications for hip, knee and partial knee replacements

FIGURE 2: above, ROSA Zimmer-Biomet robot
FIGURE 3: top right, Depuy Velys digital solution
FIGURE 4: right, CORI surgical system by Smith & Nephew

Semi-active systems lie between active and passive systems, an example of which is the application of haptics technology, whereby tactile feedback is provided by the robot arm to the surgeon to make surgical cuts within the boundaries planned by the surgeon with the software before surgery.

Some systems, e.g. MAKO® by Stryker, require preoperative CT scan imaging, while others such as NAVIO and CORI by Smith & Nephew and Rosa by Zimmer-Biomet rely on intra-operative registration of the bony anatomy by the operating surgeon.

This article focuses on robot arm-assisted total knee replacement (TKR), robot arm-assisted partial knee replacement (PKR) and robot arm-assisted total hip replacement (THR) performed utilising the MAKO® (Stryker) technology as it is a system which enables all three, i.e. TKR, PKR and THR applications, and has the most comprehensive reported outcomes data.

Robot arm-assisted knee and hip replacements

The MAKO® platform for robot-assisted TKR, PKR and THR is a closed system, meaning it only allows Stryker manufactured prostheses to be implanted. It combines preoperative imaging (CT images) with 3D technology to allow surgeons to construct a surgical plan specific to the patient's anatomy before surgery. During surgery, pins are placed around the joint which enables the process of registration, so that the robot arm and software can detect the joint in three dimensions. Precise bony cuts are then made to fractions of millimetres based on the preoperative plans. The robot system also allows for intra-operative adjustments, e.g. balancing the soft tissues during knee replacement to optimise position and alignment of the components and soft tissue balance.

Robot arm-assisted total knee replacement

TKR is a successful operation for end stage knee arthritis that has excellent survivorship and improved functional outcomes, using patient reported outcome measures (PROMs) (Hamilton *et al* 2015; Scott *et al* 2015). However, 20% of patients with knee replacements report they are dissatisfied with the procedure (Bourne *et al* 2010; Noble *et al* 2006). Outcomes of TKR are reported to be sensitive to the position of the implant and soft tissue balance (McNabb *et al* 2015), as inaccurate position and soft tissue balance may not only have an impact on clinical outcomes but may also reduce implant survivorship (Mason *et al* 2007; McNabb *et al* 2015).

When compared with manual TKR techniques, robot arm-assisted applications have been shown to increase accuracy and the precision of component positioning based on the preoperative plan (Carroll *et al* 2018). This pre-planning also takes into account the patient's anatomy and can be modified intra-operatively to address soft tissue balancing and contractures encountered during surgery. The robot arm technology has an auto switch-off option which prevents the sawblade from cutting outside the designated surgical field.

Studies show that the ability to align TKR implants according to preoperative planning is paramount to survivorship of the implant and function (Ritter *et al* 1994; Wasielewski *et al* 1994). However, although manual TKR is successful, a meta-analysis of mechanical axis alignment has demonstrated that 31.8% of manual TKRs had more than three degrees of mechanical malalignment (Mason *et al* 2007).

A more recent randomised prospective multicentre study demonstrated the clear benefits of robot arm-assisted TKR with between 36% to 47% improvement in accuracy according to the planned placement of the prosthesis compared with manual TKR, when assessing postoperative alignment, femoral and tibial component size and position (Mont *et al* 2019).

CLINICAL OUTCOMES OF ROBOT ARM-ASSISTED TOTAL KNEE REPLACEMENT

The MAKO® knee replacement system was launched in 2016, and in 2017 Marchland *et al* undertook a small, single surgeon series study of 20 matched patients, with each part of the study performed consecutively, i.e. robot-assisted TKR, followed by manual TKR. The authors highlighted the potential for better, immediate outcomes as they found that patients who had undergone robot-assisted TKR reported significantly improved pain, physical function and satisfaction scores at six months post-surgery compared to those who had manual TKR.

Kayani *et al* (2018) subsequently compared a prospective series of 40 patients who underwent MAKO® robot-assisted TKR with 40 patients who received conventional, jig-based manual TKR. The robot-assisted patient group reported less pain, lower postoperative pain requirements, less time to hospital discharge, and less time in achieving straight leg raise when compared with the manual TKR group.

Further, Denehy *et al* (2019) performed a prospective single surgeon series comparing 75 consecutive robot-assisted TKR procedures with 75 manual TKRs. Patients were followed up at one year when Satisfaction and Knee Society Scores were collected, at which time 95% of the robot-assisted TKR cohort reported being satisfied or very satisfied compared to 75% in the manual TKR group. Robot-assisted TKR had significantly reduced the length of hospital stay compared to the manual group (2.29 v 2.61, $p < 0.05$). There were, however, no significant differences in postoperative range of movement (ROM) or complications. The authors concluded that robot-assisted TKR achieves this by producing a preoperative computerised plan customised to the individual patient's anatomy. The system is then able to execute the preoperative plan with precise and accurate bone cuts during surgery whilst, intra-operatively, surgeons can precisely balance the soft tissues around the knee.

Robot arm-assisted partial knee replacements

Partial knee replacement surgery for early isolated medial, lateral and patellofemoral arthritis of the knee has been performed since the 1970s. This procedure is associated with quicker recovery, less blood loss, reduced risks of postoperative complications, and greater retention of normal kinematics of the knee when compared with total knee replacement (Price *et al* 2004; Schwab *et al* 2015; Brown *et al* 2012). Where the decision is an appropriate choice for the individual assessed, as the clinical outcomes for end-stage knee osteoarthritis are comparable, most patients would prefer to undergo partial rather than total knee replacement.

However, in spite of the evidence demonstrating the benefits of partial knee replacement, the procedure is well known to be sensitive to implant positioning and soft tissue balance (Citak *et al* 2014) and is traditionally associated with much higher risks of revision surgery compared to TKR (National Joint Registry 2022). Studies have shown that implant malalignment in PKR patients is associated with poor clinical outcomes (Citak *et al* 2014). Medial compartment knee osteoarthritis is most commonly encountered. The following discussion is limited to partial medial joint replacements with the MAKO® system.

The MAKO® PKR system was introduced in 2006 with a view to improving positioning and alignment of the partial knee implant and soft tissue balance, therefore restoring normal knee kinematics, improving clinical outcomes and longevity of partial knee replacements (Kleeblad *et al* 2018). The system utilises a Stryker prosthesis (MCK Restoris). It is designed to accurately position the partial knee implant and reduce the degree of error associated with component placement, enabling the surgeon to balance the soft tissues around the knee during surgery, with the goal of precisely replicating the native knee's kinematics.

Bell *et al* (2016) reported on a randomised controlled trial of 120 patients comparing those who had MAKO® partial knee (n=62) with those who had received manually implanted partial knees (Oxford Knees n= 58). Comparisons were made between the preoperative plan and what was achieved after surgery. The robot-assisted group revealed more accurate component positioning compared to those with manual implants and it was concluded that the MAKO® PKR more consistently placed the partial knee implant in accordance with the preoperative plan.

"STUDIES SHOW THAT IMPLANT MALALIGNMENT IN PARTIAL KNEE REPLACEMENT PATIENTS IS ASSOCIATED WITH POOR CLINICAL OUTCOMES"

A large multicentre study demonstrated that robot-assisted PKR resulted in 98.8% survivorship in 909 knees at 2.5 years follow-up (Pearle *et al* 2017) and 97% in 432 knees at 5.5 years follow-up (Kleeblad *et al* 2018). These survivorship rates are greater than the National Joint Registry (2022) data for conventional partial knee replacements and for high-volume surgeon data. The studies concluded that the greater survivorship of the partial knee replacements was due to the MAKO® partial knee system being able to more accurately achieve better component positioning compared to manual techniques.

The requirement for early revision surgery may provide clues in relation to long-term survivorship of any implant. A randomised controlled study (Gilmour *et al* 2018) compared patients who underwent medial partial MAKO® replacement (Restoris MCK; Stryker) with the conventional Oxford partial medial manual replacement. The robot-assisted partial knee demonstrated 100% survivorship compared to 96.3% in the manual group two years after surgery. The Australian National Joint Registry also noted that the revision rate for MAKO® partial knee replacement (Restoris MCK; Stryker) is 0.8% compared to the cumulative revision rate for primary conventional total knee replacement of 1% at one year (Australian National Joint Registry 2017).

CLINICAL OUTCOMES OF PARTIAL KNEE REPLACEMENT

A randomised clinical trial (Blyth *et al* 2017) demonstrated that patients who underwent the MAKO® partial knee system had median pain scores that were 55.4% lower during a 90-day postoperative period compared to patients who had undergone manual PKR.

Improving patient satisfaction after knee replacements generally is a major factor driving research and innovation in robotics technology, and this was demonstrated in the previously mentioned multicentre trials by Kleeblad *et al* (2018) and Pearle *et al* (2017), in which 92% and 91% respectively of patients reported satisfaction with their PKR. A similar, earlier study based on the Swedish Knee Arthroplasty Registry revealed that 83% of patients were satisfied with their manual partial knees at an average six-year follow-up (Robertsson *et al* 2000).

The best possible outcome after knee replacements generally are patients who can say they have "forgotten" their knees. Zuiderbaan *et al* (2015) found that one- and two-years post-surgery patients with robot-assisted PKR were more likely to have "forgotten" their knees compared with those who had undergone manual TKR.

FUNCTIONAL OUTCOMES AFTER PARTIAL MEDIAL KNEE REPLACEMENTS

Gait analysis was used to compare the outcomes of robot-assisted PKR. This consisted of 31 MAKO® (MCK Restoris) replacements with 39 Oxford manual PKRs (Motesharei *et al* 2018). Both groups were compared with a control group of healthy subjects. The robot-assisted group achieved a higher knee excursion, i.e. 18.0°, SD 4.9° compared to 15.7°, SD 4.1° in the manual group. There was no significant difference between the MAKO® partial knee group and the healthy group, but a significant difference between the manual group and the healthy group. The findings suggested that the improved alignment offered by the robot-assisted PKR improved function of the knee during gait, and that the use of the MAKO® system resulted in a gait pattern that facilitated the normal function of the knee more closely than the manually implanted (Oxford) replacement knee. Earlier, Coon *et al* (2017) had shown that 90.9% of patients with partial medial, lateral, bicompartmental and patellofemoral replacements were walking without support three weeks after surgery and that 86% of patients who had employment at the time of their surgery returned to work six weeks later.

In conclusion, PKR has the potential to achieve precise implant positioning and soft tissue balance. Improved early outcomes are reported. Surgeons are more likely to consider PKR with robot-assisted technology, as they are more confident of achieving what was planned before surgery. Patients undergoing robot-assisted PKR have reported improved satisfaction levels, better function and a "forgotten" joint.

In my practice, the MAKO® partial knee system has certainly given me more confidence that the technical outcome mirrors what was planned for the individual patient before surgery. As a result, I am more likely to advise patients with localised severe knee osteoarthritis, through use of the "finger test" that denotes localised osteoarthritis, as highlighted on page 26, to consider partial replacement surgery, rather than TKR.

Robot arm-assisted total hip replacements

Total hip replacement (THR) has been and remains one of the most successful procedures in orthopaedics since the late 1960s (Knight *et al* 2011). However, clinical outcomes following THR are influenced by patient demographics, implant factors and surgical techniques (Callanan *et al* 2011). For example, implant malalignment is directly associated with hip dislocations and mechanical loosening, both of which account for 40% of THR revisions (Bozic *et al* 2009). The MAKO® total hip replacement system was introduced

> "TECHNOLOGY OFFERS THE OPPORTUNITY FOR PERSONALISED TREATMENT PATHWAYS, WITH BETTER ADVICE AND IMPROVED RECOVERY TIMES AND OUTCOMES"

in 2010, and obtained FDA approval in 2015, with a view to consistently ensuring accurate and precise implant position and alignment, thereby improving clinical outcomes.

In clinical practice, the main technical complications that we want to avoid are hip dislocations and leg length discrepancies. With increasingly younger and more demanding patients, we also require very precise and accurate component positioning to ensure patient satisfaction and longevity of the hip replacement.

The risk of hip dislocation is reduced if the acetabular component is placed within what is referred to as Callanan and Lewinnek "safe zones" of implant position in the acetabulum, i.e. 30° to 45° inclination and 5° to 25° anteversion. A study, involving six surgeons in a single institution, evaluated 1,980 THR procedures, and showed that robotic arm-assisted THR surgery resulted in a significantly greater percentage of acetabular components implanted in a "safe zone" compared with navigation and fluoroscopy, i.e. x-ray-guided approaches (Domb *et al* 2015), meaning that there is a reduced risk of hip dislocation in these patients.

CLINICAL AND FUNCTIONAL OUTCOMES

A study comparing 100 patients with robot arm-assisted THR, with a consecutive group of 200 with manually performed THR, found that the robot-assisted group had significantly improved pain based on the Harris Hip Scores, and function on the UCLA activity scores when compared to the manual THR group (Bukowski *et al* 2016).

In a later study, Perets *et al* (2018) reported on outcomes using the Forgotten Joint Score (FJS) following robot-assisted THRs and found a FJS-12 of 83.1, which to date is the highest score found in the literature following THR. Furthermore, at two-years post-surgery no evidence of leg length discrepancy or dislocation was reported in this series.

This study also demonstrates a high, i.e. 9.3 out of 10, satisfaction rating after surgery.

Heng *et al* (2018) and Banchetti *et al* (2018) each evaluated the length of hospital stay and demonstrated that patients in the robot-assisted THR group spent less time in hospital compared with those who had undergone conventional manual hip replacements.

Summary

Robot-assisted joint replacement systems offer surgeons the potential to improve their technical approach to surgery, with the aim of improving clinical outcomes, whilst reducing the risks of complications. This is achieved through the technology that enables better pre-surgery planning, the production of an individualised operative plan, the ability to execute that plan accurately and precisely, and the capability to make intra-operative adjustments with detailed data that is not available with traditional manual techniques.

The early reported literature for the MAKO® robot arm-assisted applications for partial and total knee replacement and total hip replacement would suggest improved clinical outcomes, higher patient satisfaction, reduced pain and shorter hospital stays.

Introducing robot-assisted systems, however, involves a learning curve for surgeons and theatre staff, and during this period can result in increased costs and operating times, and the risk of introducing complications not encountered in manual non-robotic surgery. The potential benefits of robotic systems must therefore be weighed against these factors, particularly for generally successful operations such as total hip and knee replacements. Medium- and long-term studies are required to evaluate each robotic system on its own merits, and take into account the advantages and disadvantages in order to determine its role in the future of joint replacement surgery of the hip and knee.

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About the author

Winston Kim is a Consultant Orthopaedic Surgeon and specialist in hip and knee surgery. He is currently in full-time private practice at the Alexandra Hospital, Cheadle and Spire Manchester. His practice is focused on managing arthritic conditions of the hip and knee. Mr Kim performed the largest number of robot-assisted joint replacements in the United Kingdom *(Year-end 2022, MAKO® hip, knee and partial knee replacements, more than 300 cases, total experience of more than 750 robot assisted hip, knee and partial replacements performed)*. Mr Kim was a substantive Consultant Orthopaedic Surgeon at Salford Royal NHS Foundation Trust (2007-2017), and Honorary lecturer at the University of Manchester and Senior Lecturer at the University of Salford.

Video resources

Link to robot-assisted total knee replacement video:
https://www.youtube.com/watch?v=m2yE2AR99kU&t=2s
Link to robot-assisted total hip replacement video:
https://www.youtube.com/watch?v=5QKDEplv-l4

Author note

There was no conflict of interest in producing this article. Mr Kim has not received any royalty or consultancy fee from any of the robot-assisted systems in this article. He has implanted hip, knee and partial replacements using MAKO® (Stryker) and NAVIO (Smith & Nephew) systems.

REVIEW SUPPORTING QAP

I was delighted to review this article on robotic assisted (RA) orthopaedic surgery from Winston Kim, a highly respected Orthopaedic Consultant. It has been a while since I observed an orthopaedic procedure and, although I was aware that there is an increasing use of robotics in orthopaedic surgery, I was not so knowledgeable of what this actually meant, or of the potential impact for patients. Joint replacement knee and hip surgery is common and deemed successful but is still not without issues. With a reported 20% dissatisfaction rate in patients following total knee replacement (TKR), anything that can impact on this figure is hugely relevant.

From our physiotherapy perspective we would like to assume that less invasive and more precise surgical intervention gives a faster and better chance of recovery. This article does offer some evidence to support this but, as the author states, until the long-term follow up data is available, it is too early to totally conclude the results.

The main role of robot assisted surgery appears to be in terms of the more accurate placement of prosthetics, for which there are some potentially exciting developments, especially in partial knee replacements (PKR). When indicated, partial knees are a really useful option, but appear to be more sensitive to placement issues, and I was unclear whether the cited research indicating > 3 degrees mechanical malalignment in a manual versus robotic assisted procedure had as much impact for a TKR. Perhaps time will tell. Equally the concept of the "forgotten" knee is exciting, but as it is in the context of RA PKR, rather than manual TKR, it was difficult to be sure how significant this was.

The implied increase in the likelihood of good outcomes in PKR, and the reduction in leg length discrepancy following total hip replacements will certainly result in more positive patient outcomes.

For physiotherapists treating orthopaedic patients, our pre-operative input, management of patient expectations, and delivery of good quality personalised rehabilitation, has a role to play in improving our patient outcomes, but this article will be really useful in helping me to monitor my patients with joint replacements a little more carefully, understand how procedures have been done, and keep an eye on outcomes and timeframes, and I look forward to reading more evidence for better outcomes as they are gathered.

Reviewer **Katie Knapton**

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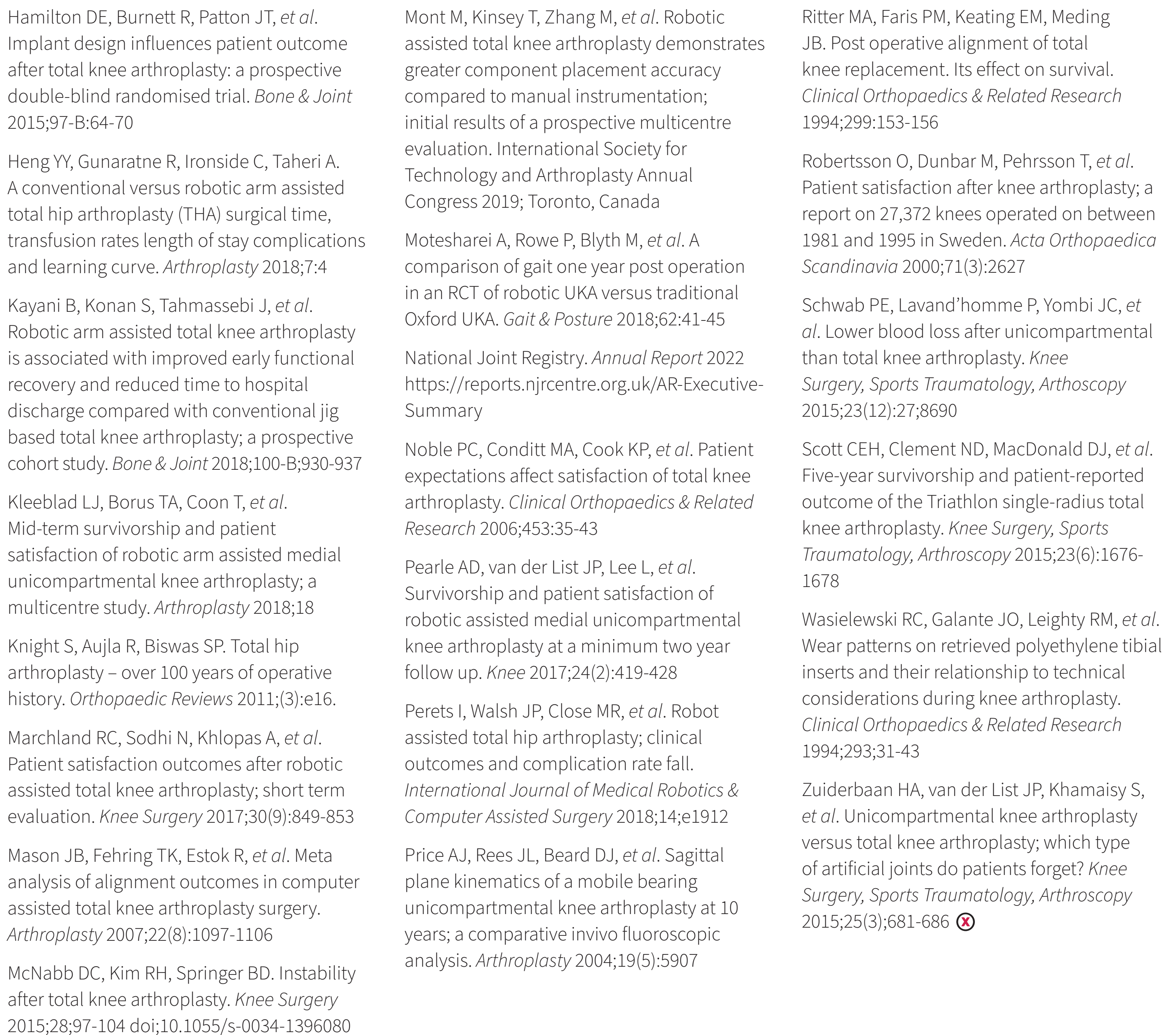

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