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Robotic-Enhanced Interventions in Total Hip Arthroplasty: Current Trends and Future Directions - A Narrative Review

Rama Rao Nadendla[1], Pushpalatha K[2], Kavitha Raja[3], Sudha D.[4], Rajkumar Krishnan Vasanthi[5], Abida Khan[6], Suria Prabha Kannaiyan[7]

[1]Chalapathi Institute of Pharmaceutical Sciences, Chalapathi Nagar, Lam, Guntur-522034, Andhrapradesh, India.
[2]JSS Medical College, JSS Academy of Higher Education & Research, Sri Shivarathreeshwara Nagara, Mysuru, India.
[3]Al Jalila Foundation Research Center, Mohammad Bin Rashid University of Medicine and Health Sciences, Dubai.
[4]Department of Physiology, Sree Balaji Medical College and Hospital, Chennai- 600044.
[5]Faculty of Health and Life Sciences, INTI International University, Nilai, Negeri Sembilan, Malaysia.
[6]Center For Health Research, Northern Border University, Arar 73213, Saudi Arabia.
[7]Department of Pharmaceutical Sciences, Chettinad School of Pharmaceutical Sciences, Chettinad Hospital and Research Institute, Chettinad Academy of Research and Education, Kelambakkam – 603103. Tamil Nadu, India.

Abstract

Background: Total Hip Arthroplasty (THA) is a widely implemented procedure for osteoarthritis (Oas), offering pain relief in most patients. The ventral method has gained popularity due to faster retrieval and a lower risk of dislocation. Still, uncertainty remains a major cause of THA.
Objectives: To evaluate robotic-assisted THA systems, surgical precision, spinopelvic dynamics, long-term results, and cost-effectiveness, addressing current gaps in the literature. A comprehensive literature review was accompanied to evaluate robotic-assisted THA, with a focus on surgical precision, spinopelvic dynamics, clinical outcomes, health risks and cost-effectiveness. Data were extracted from peer-reviewed journals, clinical trials, comparative analyses, and registry reports. Studies on various robotic systems-including MAKO, ACROBOT, ROBODOC, and T-Solution. One was examined to evaluate its involvement in implant placement, stability, and overall performance. Key themes involved imaging technologies, surgical planning software, and innovations in robotic guidance systems.
Results: The review initiate that robotic-assisted THA significantly progresses implant positioning accuracy and may diminish complication rates associated with malalignment. Robotic systems consuming CT-based or imageless navigation develop surgical accuracy, while also accounting for distinct spinopelvic dynamics. Long-term conclusion data and cost effectiveness analyses endure limited. The review highlights the essential for more robust relative studies across robotic daises and calls for integration of patient-specific anatomical and biomechanical factors to refine surgical approaches. Recognizing reliable parameters for spinopelvic mobility and their impact on postoperative significances is vital for personalized THA planning.
Conclusion: This review aims to fill gaps in published studies by analyzing long-term follow-up data and cost-effectiveness, comparing robotic systems, and prominence clinical outcomes, complications, and advancements in robotic

Corresponding Author:

Professor Suria Prabha Kannaiyan
Department of Pharmaceutical Sciences, Chettinad School of Pharmaceutical Sciences, Chettinad Hospital and Research Institute, Chettinad Academy of Research and Education, Kelambakkam – 603103. Tamil Nadu, India.

suryaapril14@yahoo.com | ORCID: 0009-0007-5644-8794

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technologies.

Keywords: Cup positioning, THA, ROBODOC, Robotic, Spinopelvic motion

Introduction

Despite advances in surgical techniques, uncertainty in implant positioning remains a critical determinant of THA outcomes. Misalignment contributes to complications such as pain persistence, instability, and early revision. To address this issue, researchers are exploring the use of computer-assisted navigation systems to improve the accuracy of implant placement during THA procedures.[1] By providing real-time feedback and guidance to surgeons, these systems have shown promise in reducing the risk of implant misalignment and associated complications. Conventional aids such as fluoroscopy and triangulation cannot consistently overcome these limitations, particularly in patients with OAs or spinal deformities. Robotic arm-assisted THA (rTHA) has emerged to address this uncertainty by improving the precision and reproducibility of implant placement, with the potential to reduce complications and optimize pain alleviation.[2] As the field of orthopedic surgery continues to advance, rTHA is becoming increasingly popular for its ability to enhance surgical efficiency and overall patient care. Although several navigation methods are available, only a limited number of robotic systems have received FDA approval, highlighting the novelty and evolving role of this technology. The anteversion (AVn) of the acetabular module cannot be consistently replicated using fluoroscopy since OAs and other degenerative spinal disorders may influence it.[3] The use of technologies in THA within the operating theater and the peri-surgical period has encountered opposition due to elevated costs, steep learning curves, and time constraints, coupled with a lack of definitive long-term data to endorse their unequivocal adoption. The use of robotic tracking does not jeopardize the paramount necessity of patient safety. The advancement of robotics in THA began with the founding of the ROBODOC organization in the late 1980s. ROBODOC, created by Dr. William Bargar, his veterinary colleague Dr. Howard Paul, and Integrated Surgical Systems, was the inaugural dynamic robotic system tailored for orthopedic surgery.[4] A computer-assisted robotic arm enhanced the training of femur bones and the implantation of devices during THA, demonstrating superior precision in both laboratory and canine models before human trials. AC-ROBOT (Active Constraint-Robotic System), launched in the mid-2000s as a semi-active robotic system for THA, utilized a synthesis of computer-assisted triangulation, anatomical techniques, and a physician-directed robotic arm to enhance graft stability and joint indication selection.[5] Unlike its predecessors, AC-ROBOT provided real-time tactile feedback to specialists during implant placement, achieving similar precision and accuracy without significant time delay. The MAKO robotic technology has recently garnered significant acclaim in the execution of THA.[6] The MAKO, a semi-active robotic device, utilizes a robotic arm and a tactile management system to aid professionals in examining peri-acetabular and femoral bone, as well as in the placement of prosthetics. T-Solution One, an advanced dynamic robotic system used in THA, combines technology from ROBODOC with modern innovations, including pre-operative planning, intra-operative navigation, and a robotic arm, to optimize the placement of acetabular and femoral implants. Robotic-assisted total joint arthroplasty (TJA) has been thoroughly investigated in this field, with the anticipation that robotic equipment can markedly enhance the precision of bone cuts, implantation, and alignment, ultimately leading to improved clinical results and prolonged graft survivorship.[7] Surgeons, recognizing the technical improvement and their expertise with the surgery, presume that robotic-assisted technology might have achieved far more; hence, they sought to use its capabilities for the amendment of TJA. Given the significant advancements in the implementation of the robotic system, the contemporary hospital environment, integrated with engineering and technology, has undergone a significant transition, altering the framework of healthcare delivery.[8] The clinic, including the active operational rooms and the precisely regulated critical care units and labs, exemplifies the omnipresence of advanced technology. Robotic-assisted surgery is at the forefront of this technological revolution, integrating machine accuracy with human surgical expertise, thereby redefining medical excellence and patient care standards. The benefits of binocular endoscopic vision, which offers an authentic 3D experience combined with user-friendly handles that mimic regular hand motions, have facilitated the extensive use of robotic surgery in general surgery, urology, and gynecology.[9] The objective of the review aimed to assess robotic-assisted THA systems with respect to surgical precision, spinopelvic dynamics, long-term outcomes, and cost-effectiveness, thereby addressing current gaps in the literature. A comprehensive search of peer-reviewed journals, clinical trials, comparative studies, and registry reports was undertaken. Evidence was synthesized across different robotic platforms, including MAKO, ACROBOT, ROBODOC, and T-Solution One, to evaluate their role in implant placement, stability, and overall performance. Key themes that emerged included the use of advanced imaging technologies, surgical planning software, and innovations in robotic guidance systems.

Methods

Search Strategy

A focused narrative review was conducted to evaluate studies on rTHA, specifically addressing surgical precision, spinopelvic dynamics, imaging technologies, cost-effectiveness, clinical outcomes, and related complications. The databases PubMed, Scopus, Web of Science, and Google Scholar were searched for studies published between January 2020 and June 2025. The search strategy combined keywords and Boolean operators as follows: "rTHA" OR "robotic hip replacement" OR "robotic joint arthroplasty" OR "MAKO" OR "ROBODOC" OR "ACROBOT" OR "T-Solution One" OR "ROSA" AND "clinical outcomes" OR "implant positioning" OR "spinopelvic motion" OR "cost-effectiveness" OR "complications." Reference lists of relevant review articles and included studies were manually screened to identify additional eligible publications. A total of 53 studies were included in this review, comprising 39 original research articles and 14 review articles, providing a comprehensive yet focused overview of current evidence in robotic-assisted THA.

Inclusion Criteria

Studies were involved if they intensive on rTHA and evaluated aspects such as surgical accuracy, implant positioning, spinopelvic motion, cost-effectiveness, or clinical outcomes. Research connecting robotic platforms like MAKO, ROBODOC, ACROBOT, ROSA, Intellijoint, and T-Solution One was considered. Both comparative studies between robotic-assisted and manual THA, as well as observational studies evaluating robotic platforms independently were included. Eligible study types contained RCTs, cohort studies, case-control studies, systematic reviews, meta-analyses, and relevant prospective or retrospective studies published in English within the specified period.

Exclusion Criteria

Studies were excluded if they focused exclusively on other orthopedic procedures such as knee or shoulder arthroplasty, were limited to cadaveric models or biomechanical simulations without clinical correlation, or were conference abstracts, commentaries, editorials, or letters lacking original data. Non-English publications and duplicate records retrieved from multiple databases were also excluded from the final analysis.

Robots used in THA

The incorporation of advanced technology and engineering has suggestively transformed the contemporary hospital environment, predominantly in surgical practice, where robotic-assisted systems are redefining healthcare delivery standards.10 Among these inventions, robotic-assisted surgery syndicates machine precision with human proficiency to improve surgical accuracy and patient consequences. The U.S. Food and Drug Administration's approval of the da Vinci robotic system manifest a turning point in the widespread approval of robotic techniques, particularly in negligibly invasive procedures, benefiting from binocular 3D vision and ergonomic instrument control that develop surgical dexterity. This success accelerated the introduction of computer-assisted orthopedic surgery and robotic hip replacement in the early 1990s, spearheaded by the expansion of ROBODOC.[11] In the late 1980s, William Bargar pioneered the fabrication of custom grafts using computer-assisted design and manufacturing

(CAD/CAM) based on CT imaging, which laid the foundation for precision in implant alignment.[12] ROBODOC became the first surgical robot widely used THA, although a class-action lawsuit in Germany (2004) raised concerns over complications in some patients. The system enabled surgeons to preoperatively select appropriate femoral implants and machine the femoral canal accurately for a press-fit fixation. Early implementations required titanium fiducial screws in the greater trochanter and femoral condyles under local anesthesia to assist with CT-based planning. The DigiMatch system was later announced and established high accuracy, but its surgeries averaged 146 minutes compared to 121 minutes with traditional pin-based approaches.[13] Accuracy was authorized using postoperative CT scans, though protracted operative time endured a limitation. Similarly, the CASPAR robotic system displayed precise machining but was related with longer surgeries and increased intraoperative blood loss, leading to its discontinuation.[14] These limitations impelled the growth of semi-active robotic systems such as ACROBOT, developed in London, which indorsed the surgeon to guide a robotic arm within a predefined surgical boundary based on preoperative CT planning. The need for greater adaptability and real-time intraoperative control additional advanced robotic innovations, resulting in the appearance of the MAKO system. Approved by the U.S. FDA for knee arthroplasty in 2008 and hip arthroplasty in 2010,[15] MAKO integrates preoperative CT scans to create a 3D model of the pelvis and proximal femur, allowing optimal component alignment. During surgery, pins are placed in the iliac crest and intertrochanteric ridge for stability, while the robotic arm assists in precise femoral neck osteotomy and component positioning based on templated parameters such as the center of rotation (COR).[16] The MAKO system employs an active constraint model that restricts deviations from the surgical plan through multimodal feedback, including tactile resistance, auditory alerts, and visual color-coded cues, thus ensuring precise acetabular and femoral preparation (Figure 1).

Figure 1: MAKO robotic arm is affixed to an acetabular reamer to deliver input and direct the surgical reaming of the acetabulum throughout the procedure.[17]

Spinopelvic motion and its parameters

A prominent topic related to instability after THA is the dynamic interaction between the pelvis and lumbar spine, commonly referred to as spinopelvic motion.[18] This area remains under active investigation, with studies reporting varying conclusions. Clinically, spinopelvic imbalance and a history of spinal fusion surgery are considered strong predictors of postoperative hip instability. Several factors influence stability, including the extent of the spinal fusion, involvement of the lumbosacral junction, the type of lumbar procedure, and the timing of the fusion. Valuation of spinopelvic motion can be stimulating; therefore, researchers mainly focus on three measurable parameters: sacral slope (SS), lumbar lordosis (LL), and the anterior pelvic plane (APP).[19] In individuals with normal mobility, standing posture is categorized by extended hips, anterior pelvic tilt, and LL, which together induce posterior pelvic tilting, resultant in approximately a 0.8° increase in acetabular AVn for every 1° of posterior pelvic tilt.[20] Unpredictability or rigidity of the lumbar spine may arise following spinal surgery or degenerative lumbar arthritis. Lumbar imbalance is normally assessed by subtracting LL from pelvic incidence (PI), with a value ≤10° (PI−LL ≤10°) indicating alignment.[21] APP and SS-based radiographic approaches are also used to evaluate spinopelvic inequity. Reduced lumbar mobility requires the hip joint to compensate with a greater range of motion during daily activities; patients unable to achieve this due to impingement face a higher risk of postoperative dislocation. Spinopelvic hypermobility, defined as an SS change >35° between standing and sitting,[18] can also predispose patients to instability, often associated with impingement. Notably, severe contralateral hip osteoarthritis is the strongest predictor of persistent spinopelvic hypermobility following THA. Since the pelvis functions as a dynamic unit, spinopelvic motion must be carefully considered when determining the optimal functional implant position, which incorporates both the anatomical placement of the acetabular cup and pelvic orientation. Personalized planning based on patient-specific safe zones is increasingly emphasized, as native spinopelvic architecture significantly influences hip biomechanics. Spinopelvic motion also induces a biological expansion of the functional acetabular cup by altering AVn and inclination.[22] In contrast, patients with a rigid spinopelvic construct demonstrate limited posterior pelvic rollback, requiring greater hip flexion when seated and increased extension when standing, which elevates the risk of instability.

Clinical importance

The clinical use of this information remains contentious, and the analysis of overarching trends suggests that a slight augmentation of acetabular AVn by 5°-10° may be beneficial in treating the majority of individuals exhibiting diminished spinopelvic mobility.[23] The labor-intensive equipment of the acetabular element does not consistently facilitate precise placement by the specialist. Certain specialists choose to use fluoroscopy for cup alignment; nevertheless, its reliability for modifying AVn is inadequate. Surgeons have explored other approaches to enhance stability, comprising elevated offset stems and various mobility bearings that facilitate the utilization of a larger diameter head. While robot arm-assisted technology can precisely implement the pre-operative plan, adjustments to the plan are often necessary during the operation for the positioning of revision implant components or augmentations. Despite the modern robotic arm-assisted method enabling specialists to modify implant location and size intraoperatively at any point, manual bone cutting remains necessary, necessitating the surgeon's critical thinking and problem-solving skills.[24]

Fluorescent based robotics

The Velys Hip Navigation device offers real-time surgical guiding via fluoroscopy by integrating preoperative plain radiographs with intraoperative fluoroscopic images.[25] This fusion allows accurate assessment of acetabular AVn, Inclination, leg length discrepancy (LLD), and offset.[26] The Cuptimize Hip-Spine Analysis software has recently enhanced preoperative planning by evaluating the spinopelvic relationship. This technique uses preoperative plain radiographs to obtain spinopelvic features and subsequently delineates a dynamic functional, safe zone for surgery. The technology relies only on fluoroscopy, without arrays or pins, hence limiting the surgeon's ability to use real-time input for implant location. The ROSA Hip System is an image-guided platform that employs solely conventional radiography and fluoroscopy. Preoperative planning incorporates spinopelvic considerations characteristics to delineate a precise safe zone for implant placement. Unlike some systems, it does not utilize tracking arrays that necessitate Intraoperative fluoroscopy for real-time feedback. Fluoroscopic images are transmitted to the ROSA system during operation to deliver information on cup AVn, inclination, offset, and LLD.[27] However, it does not provide data regarding the hip COR, nor does it offer tactile feedback. Although the ROSA Hip System lacks real-time assistance during reaming, it provides input during the final implant positioning to aid in the precise placement of the acetabular component within the defined safe zone. The surgical planning instrument utilizes preoperative X-rays as a reference (Figure 2).

Figure 2: ROSA system, involving an illustration of a planning system.[17]

Software

The software platform of the robotic structures may be categorized as 'closed' or 'open' depending on the restrictions placed on implantation selection. Robotic systems using open platforms, such as ROBODOC, deliver compatibility with various implantation manufacturers and proposals, thereby allowing surgeons more autonomy in selecting implants customized to the patient's anatomy. Contemporary robotic systems are mostly closed platforms, such as MAKO, which restricts implant selection and precludes various configurations for multiple prostheses, necessitating that surgeons use alternative implants that diverge from their customary practices to operate these robotic systems.[28]

Cup positioning in THP

Misalignment of the acetabular cup is associated with complications such as dislocation, psoas tendon impingement, bony impingement limiting range of motion, leg length discrepancy, and increased wear conditions that may necessitate revision surgery.[29] The key attributes employed to define cup positioning are version and inclination Figure 3. The version denotes the cup's orientation inside the sagittal plane. Increased AVn facilitates greater joint angle reduction and inward movement of the hip prior to the onset of impingement Figure 5. Simultaneously, elevated AVn may increase the chance of ventral dislocation, while diminished AVn or retroversion is associated with an augmented threat of posterior displacement. Predisposition refers to the positioning of the cup inside the coronal plane. The specified area exhibited an inclination of 30-50 degrees and an AVn of 5-25 degrees, to reduce the danger of dislocation.[30] Positioning the implant cup accurately might be difficult. Anatomical landmarks may determine the positioning of the acetabular component. Misidentification of landmarks might result in an error in the final cup placement. Soft tissue contractures, anatomical alterations resulting from osteophytes or prior trauma, and anatomical variations linked to hip dysplasia may lead to inaccuracies in the precise identification of anatomical landmarks. A five-step approach is used to determine intraoperative acetabular AVN, inclination, and LLD by analyzing screenshots of fluoroscopic images. A fluoroscopic image of the AP pelvis is acquired to assess the inclination concerning the inter-teardrop line, along with the analysis of additional parameters following the insertion of the femoral component. The radiographic overlay technique utilizes software to analyze intraoperative pictures by contrasting the operating side with the contralateral side according to user-defined reference points.[31] For each fluoroscopic image, the overlay system produces an ellipse according to the established criteria for the cup's placement. This may serve as a reference for component placement throughout the surgical procedure. The application of such software enhanced the precision of cup placement relative to cups organized without supplementary software. Non-imaging navigation techniques determine the implant's position relative to a reference plane shown in Figure 4. The reference is often the ventral pelvic plane, which must be delineated by the surgeon who identifies the critical anatomical features at the onset of the treatment. The tracker antenna is positioned adjacent to the superior ventral iliac crest, and the surgeon recognizes

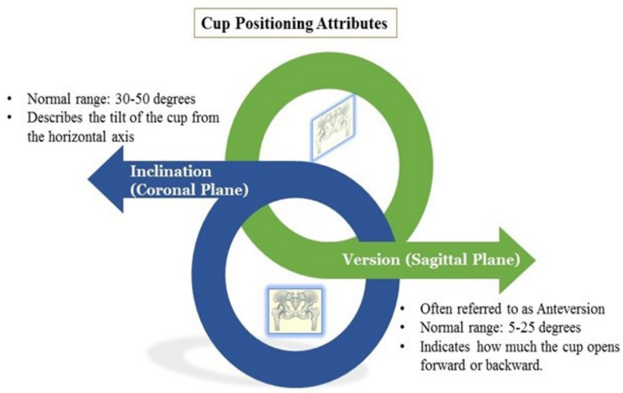

Figure 3: Cup Positioning Attributes

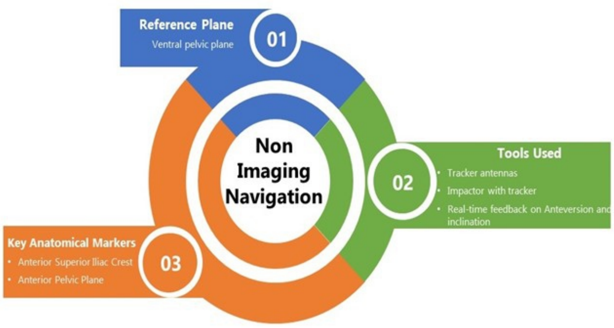

Figure 4: Non-Imaging Navigation of Cup Positioning

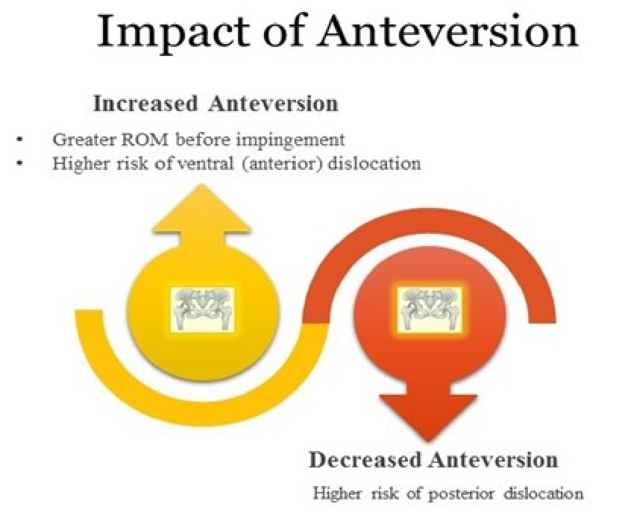

Figure 4: Non-Imaging Navigation of Cup Positioning

additional anatomical features to ascertain the anterior pelvic plane.[32] An extra tracker may be affixed to the impactor during acetabular reaming. The workstation calculates the connection between the trackers and the camera, displaying inclination and AVn on the monitor in real-time.

Imageless robotics

Intellijoint Surgical, an imageless method that utilizes markers affixed to the pelvis to generate a 3D model, requires anatomical markers identified by the surgeon during the procedure for the formulation of the medical plan. It facilitates intraoperative input about cup positioning, hip COR, LLD, and offset. The system allows for the preoperative entry of spinopelvic data via plain radiographs, providing a functional component location for the surgeon's intraoperative targeting. This technology enables the design of both the SS and APP, offering additional information for the surgeon's use. Additional imageless systems include HipAlign, NaviSwiss, Real Intelligence Hip Navigation (Smith & Nephew), and NaviPro Hip (Kinamed).[33]

CT based robotics

The MAKO system (Stryker), approved by the FDA, is a widely used CT-based navigation platform that employs a semi-active robotic arm to assist surgeons during rTHA.[34] Pre-operative CT scans are uploaded to the MAKO software, which assimilates advanced planning tools and anatomical markers to assess leg length, femoral offset, three-dimensional acetabular cup sizing, AVn, predisposition, hip center of rotation, and cup coverage. Pre-operative lateral pelvic radiographs are also examined to assess spinopelvic characteristics, with the system automatically manipulative parameters such as SS and PT. This allows a dynamic preoperative assessment, allowing surgeons to pretend hip range of motion, identify potential impingement zones, and optimize implant alignment. When inconsistencies in native femoral AVn are observed, acetabular constituent positioning can be adjusted accordingly, although metaphyseal-fitting stems allow safe version changes only within a 5°–10° range.[35] Numerous studies have established the successful application of MAKO-assisted rTHA in complex scenarios, including developmental dysplasia of the hip, ankylosing spondylitis, and post-traumatic arthritis. Intra-operatively, the system uses pelvic arrays for real-time navigation, eliminating the need for fluoroscopy and subsidiary various approaches, such as ventral, anterolateral, and posterior techniques. Throughout reaming and cup placement, the robotic arm provides tactile feedback, ensuring precise adherence to the pre-operative plan. The Enhanced Femoral Workflow enables accurate femoral preparation, enabling high precision even for less experienced surgeons.[36] Relative studies have shown that MAKO-assisted procedures realize more consistent acetabular positioning within the desired safe zone, although operative time is typically 12 minutes longer than conventional manual THA.[37] Most robotic THA platforms rely on preoperative CT scans to generate 3D reconstructions of patient anatomy and create individualized surgical plans, which recover implant compatibility, optimize component sizing, and enhance accuracy in alignment. The integration of 3D imaging further minimizes magnification errors and reduces inconsistency in femoral canal measurements compared to conventional radiographs. Specifically, for semi-active robotic systems like MAKO, high-resolution CT imaging of the pelvis and proximal femur provides critical anatomical data, including pelvic tilt, which plays a key role in ensuring accurate acetabular component placement.[38]

CT-Based Modeling and Registration Techniques

CT scan results remain loaded into the pre-operative terminal for cybernetic preparation and implementation. In semi-active robotics, a three-dimensional prototype, a digital model of the individual's pelvis and proximal femur, is subsequently produced using computer software.39 Specific anatomical landmarks are then delineated on the models and recorded during the operation. Fiducial markers, namely locator pins implanted in bone, were employed for the registration of the patient's anatomical landmarks inside the robot coordinate system of the CT image. Difficulties associated with pin-site, including postoperative discomfort and infection, have diminished their use as fiducial markers, leading to their current application in fixation.[40] This has resulted in the establishment of surface registrations of the landmarks to provide information on the spatial orientation of the bone about the robotic system. In fully functioning robots, specific landmarks are unnecessary; surface matching is executed, aligning computer models of implants or equipment with actual implant locations by utilizing coordinates of the individual's pelvis and proximal femur, which are later generated using computer software.[41] Specific anatomical landmarks are then delineated on the models and recorded during the operation. Consequently, fully active systems are designed to enhance the precision of the dimensions and placement of the femoral component. The operative system for the acetabulum is presently unavailable.[42] Most semi-active systems utilize tactile robotic arms equipped with reaming instruments for acetabular preparation, aligning with the preoperative plan.[43] The system exclusively controls size and alignment, while the robotic arm facilitates acetabular reaming with constant tactile feedback from the surgeon. The surgeon controls the reaming end of the robot's haptic arm, while the robotic system restricts unwanted movement beyond the reaming route limit established by preoperative 3D modeling. This reduces unintentional offline or excessive reaming during acetabular preparation.[44] These instruments enable pre-operative planning of the femoral component and intraoperative evaluation of femoral offset, leg length, and anatomical variation of the femur. Nonetheless, it omits robotic milling or reaming of the femur. In fully active robotic total hip arthroplasty, reaming is conducted with continuous saline irrigation, and the stem is inserted into the femoral canal following standard technique.[45] The osteotomy site at the femoral neck is established by a notch in the medial cortex. The semi-active tactile system utilizes a robotic arm to position the final acetabular component through a tactile tunnel, thereby ensuring the final placement aligns with the preoperative design.[46] In THA, planning requires adequate imaging to understand the relevant patient anatomy and to determine the most appropriate implant and its ideal placement for the patient.

Cost Effectiveness

The initial investment, maintenance, and consumables are direct expenditures linked to rTHA. The cost of acquiring a robot may vary, starting from $711,000 to $1.36 million, and a yearly servicing agreement is also necessary.[47] Indirect expenses include operational time, adjustment rates, problems, duration of hospital stay, emancipation disposition, and reintegration. Patients who underwent rTHA exhibited a markedly reduced likelihood of necessitating admission to inpatient rehabilitation or skilled nursing facilities and required fewer home health service visits. The average post-index expenses for rTHA were 13% lower than those for mTHA.[48] Disposable items constitute a significant percentage of the expenses associated with rTHA; however, these costs may be mitigated, to some degree, on an individual surgeon's basis. For instance, while using MAKO in the execution of rTHA, some secures and barriers may be disregarded. A permanent point might have been utilized on the pelvic array or proximal femur instead. The specialist may choose to employ two pins for the pelvic array rather than three. The primary disposables need for the implementation of an MAKO rTHA include a shutter for the robotic arm, two pins, and a package of sterile discs for the array. The need for comprehensive teaching and the related education curve of robotic-assisted operations may result in extended operating periods during the early stages of deployment. This not only escalates clinical costs but also requires additional resources for training the surgical team.[49] It is expected that, over time, as surgeons refine their skills, the duration of procedures would achieve greater regularity. Moreover, extended operational durations during the training phase of the surgical team might lead to increased costs.[50] These expenses may be mitigated if robotic surgery demonstrates a reduction in opiate analgesic use, a decrease in hospital length of stay, a lower incidence of readmissions, and fewer releases to post-acute rehabilitation facilities associated with traditional arthroplasty. The usage of a robotic THA system includes expenses such as robot installation and associated software, yearly maintenance fees, training for surgical personnel, equipment procurement, sterilization, and supplementary expenditures related to preoperative imaging. Justifying the substantial start-up expenses may be challenging since the current body of research has not shown any meaningful differences in results. Due to the limited number of firms producing surgical robots, the initial investment is estimated to exceed one million dollars for the robot alone, excluding implants, disposable equipment, yearly service, and maintenance expenditures.[51] There are economic benefits to cogitate. Decreased impediment and re-operation rates mitigate the substantial initial expenses over time, as may a reduced quantity of trays, which lowers sterilization costs.

Complications

Prosthetic joint contamination may be disastrous, and the reduction of hazard and administration of contagion are crucial when evaluating consequences related to hip arthroplasty.[52] Theoretically, an increased infection risk may arise from a higher number of operational room workers and the supplement of more bone pins. At the same time, the robotic arm's positioning above the specialist or assistant's chest might jeopardize sterility during early practice. Minimizing blood loss may expedite recovery duration and decrease hospital stay length. Previous research indicated that operations with ROBODOC resulted in increased intraoperative blood loss; however, subsequent trends have been ambiguous. Although the education curve related to the implementation of robotic THA in clinical practice is primarily linked to time and effectiveness, numerous studies have demonstrated accuracy and outcome metrics. The use of robotic-assisted technology alleviated the knowledge curve for the novice surgeon, as shown by the absence of substantial differences in radiological results and surgical duration between the ventral and subsequent approaches to THA when juxtaposed with a qualified surgeon. Enhanced precision in cup positioning results in superior functional outcomes and increased prosthesis longevity.[53]

Future Research Perspectives

Future research should prioritize the assessment of long-term clinical outcomes to determine the durability, functional benefits, and patient satisfaction associated with robotic-assisted THA. Comparative studies between different robotic platforms are essential to evaluate variations in accuracy, efficiency, learning curves, and cost-effectiveness. These studies will provide valuable insights into the overall effectiveness of robotic-assisted THA and help guide surgeons in selecting the most suitable technology for their patients. Considerate the long-term implications of using robotic assistance in THA will also inform healthcare policies and reimbursement strategies. By focusing on these key areas of research, the orthopedic community can continue to improve surgical outcomes and patient experiences in the field of rTHA. Efforts should also focus on the development of next-generation robotic technologies, including enhanced software algorithms, advanced imaging modalities, and enhanced haptic or feedback systems, to further optimize surgical precision, ensure patient safety, and enable highly individualized, patient-specific planning and execution in total hip arthroplasty.

Conclusion

In conclusion, robotic-assisted THA has evolved significantly, with advancements in robots used in THA enhancing surgical precision. The integration of spinopelvic motion parameters and fluorescent-based robotics has further refined the procedure's outcomes. Optimized cup positioning, facilitated by robotic guidance, ensures improved joint stability. Advanced software and CT-based robotics offer greater accuracy in preoperative planning and intraoperative execution. Imageless robotics presents a promising development, reducing reliance on preoperative imaging. This review emphasizes the significance of robotic systems in THA, highlighting their potential to enhance clinical outcomes, streamline procedures, and inform future research for further technological advancements in orthopedic surgery.

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Conflict of Interest

The authors declare no conflicts of interest.

Abbreviations

Total hip arthroplasty (THA)
Total joint arthroplasty (TJA)
robotic-arm-assisted Total hip arthroplasty (rTHA)
limb length discrepancy (LLD)
ACROBOT (Active Constraint Robotic System)
computed tomography (CT)
sacral slope (SS)
Lumbar Lordosis (LL)
Anterior Pelvic Plane (APP)
leg length discrepancy (LLD)
center of rotation (COR)
osteoarthritis (Oas)
anteversion (Avn)

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