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Topic: Evaluating the benefits and limitations of Robotic assistant surgery in orthopedics.

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Abstract

The main advantages of robot-assisted orthopedic surgery over conventional orthopedic techniques are improved accuracy and precision in the preparation of bone surfaces, more reliable and reproducible outcomes, and greater spatial accuracy. Robotic systems are well suited for use in orthopedic surgery. Robotic devices can be firmly attached to bones by isolating and strongly fixing them in certain locations. The computer control of the robotic system is made simpler by treating the bone as a fixed object. Commercially available robotic systems fall into one of two categories: positioning, milling/cutting, or passive/active devices. Although computer-assisted orthopaedic surgery is a similar field of orthopaedic technological advancement, robot-assisted orthopaedic surgery can attain levels of safety, accuracy, and precision that computer-assisted orthopaedic surgery cannot. Robot-assisted orthopedic surgery is now being researched for use in trauma and spinal surgeries, total hip and knee replacement, and tunnel implantation for knee ligament reconstruction. There are no published long-term statistics defining the effectiveness of robot-assisted orthopedic surgery, despite a number of short-term research showing the viability of robotic applications in orthopedics. Before robot-assisted orthopaedic surgery is generally accessible, concerns about cost, training, and safety need to *be resolved. Although it is still extremely early in its development, robot-assisted orthopaedic surgery has the potential to revolutionize orthopaedic operations in the future.*

Keywords: *Robot-assisted orthopedic surgery (RAS), Robot-assisted, radiation exposure, randomized controlled trials (RCTs), TiRobot-assisted technique.*

Contents

Overview

The integration of robotics has heralded a new era in orthopaedic surgery. The development of extremely complex robotic systems as a result of groundbreaking technology breakthroughs has completely changed the way joint and bone operations are carried out. These state-of-the-art devices offer unmatched accuracy and efficiency in orthopedic procedures by fusing the precision of artificial intelligence with the knowledge of experienced surgeons.

This paradigm shift in orthopaedics speeds up post-operative recovery, minimizes patient discomfort, and lowers the margin of error. This article will examine the astonishing capabilities, advantages, and future potential of robotic orthopaedic surgery, a cutting-edge technology that promises a better and more pain-free future for people in need of joint and bone interventions.

1. Introduction

There are many advantages to the use of surgical robots. In general surgery, they improve dexterity and hand-eye coordination, they can provide the surgeon with a more ergonomic position and make surgical approaches possible that were previously thought technically impossible [1]. Additional benefits include the possibility to perform telesurgery, which reduces radiation exposure, a greater range of motion, and improved three-dimensional (3D) visualization in comparison to laparoscopic operations [2,3]. One of the biggest barriers to the widespread use of robotic surgery is the initial investment needed, as the majority of surgical robots cost between $1 and $2,5 million [4]. The size of the devices, the loss of haptic sense, and the need for skilled personnel in the operating room are further drawbacks. As is frequently the case with technical advancement, these drawbacks might get better with time.

The distinction between computer-assisted surgical navigation and robot-assisted surgery should be made clear for the purposes of this review. Any computer-based process that plans and executes surgical procedures using cutting-edge technology, including 3D imaging or augmented reality, is referred to as computer-assisted surgical navigation. In robotic surgery, a sophisticated surgical robot is used, and the surgeon may or may not be at the operating table. A surgical robot is a computerized device that can help with surgical navigation. Typically, it has an arm that can execute specific surgical operations with the use of tools like a guide sleeve attached to the arm.

In other cases, the surgeon does not need to be in the operating room at all (telesurgical operations), and robots can be partially or fully autonomous. It should be mentioned that computer-assisted navigation systems are compatible with the majority of robotic systems [5,6,7]. In conclusion, while not all computer-assisted surgical navigation systems are robots, surgical navigation is aided by robots in surgery.

A few review studies examining the use and effectiveness of robotics in orthopaedics have been conducted [8]. It has been demonstrated that using robots to implant pedicle screws during spine surgery produces better results than using traditional methods [9]. Although robots have been utilized for hip and total knee replacements, there is no concrete proof that they are better than the traditional method because robotic surgery groups have greater rates of complications, longer recovery times, and higher costs [10].

These review articles primarily addressed elective orthopaedic surgery, even if they also purport to examine trauma [11]. An overview of the current uses in traumatology is given by this review, which looks into robot-assisted fracture fixation in orthopaedic trauma surgery. Investigating the use of robot-assisted surgery and its impact on surgical outcomes in patients with orthopaedic trauma is the goal of this study [12]. Digital optics, digital imaging, visual displays, computer-assisted navigation systems, software applications (which occasionally incorporate artificial intelligence), augmented reality, and robotic arms are some of the various parts that make up robotic surgical systems. For implant or pedicle screw insertion, image-based techniques frequently employ software to transform anatomical pictures from intraoperative or preoperative imaging (usually CT scan) into a virtual 3D reconstruction of the joints or spine [13].

In order to optimize limb or spine alignment and reduce soft-tissue and bone damage, surgeons can use this 3D model to design the procedure and guarantee correct implant and tool placement [14]. Others are "imageless," registering and establishing bone landmarks during surgery after using preoperative imaging for surgical planning [15]. Systems differ in how actively the surgeon participates in resection. While the robotic surgical system is engaged in doing the resection in certain systems, the surgeon is active or partially active in others.

Robotic surgical systems are a class of technology that allow for more accurate and precise implant placement during orthopedic procedures. This leads to better function and mobility, fewer problems (such blood loss), and a lower need for early revision surgery.Robotic systems have been developed for three main orthopedic surgery categories: complete and partial knee replacement, total hip replacement, and spinal surgery, which mainly involves the insertion of pedicle screws during spinal fusion procedures [16,17].

2. Methodology

An extensive exploration of pertinent reviews and articles was conducted through the utilization of the PubMed and Google Scholar databases. In this review, we can mainly focus on 'Evaluating the benefits and limitations of Robotic assistant surgery in orthopedics' mainly focusing on benefits and limitations. Also, by tracking the citations of the papers that were retrieved, more pertinent articles were found using Google Scholar.

Inclusion and Exclusion Criteria: Inclusion criteria for further analysis were based on the following: (a) article describing a clinical study on the application of robotic surgery in orthopedics; and (b) review article, meta-analysis, clinical trial, and guideline. Exclusion criteria were book chapters, conference proceedings, animal studies, and cadaveric investigations.

3. Limitations of Robotic-Assisted Systems

The long learning curve for the surgeon and surgical team, the cost of installing and maintaining the robotic devices, the femoral and tibial incisions for the insertion of the registration pins, the eventual need for additional imaging for the preoperative plan with increased radiation exposure (when considering image-based systems), and other limitations have all been addressed in relation to robotic-assisted total knee arthroplasty [18].

Additionally, because the first generation of robotic devices required longer surgical times, there have been reports of higher blood loss and extended anesthesia [19,20]. In robotic-assisted procedures, the choice of implant is frequently restricted by whether a robotic system uses a "open" or "closed" platform. While open platforms (like the ROBODOC system) allow the surgeon to use multiple implants from different companies based on their preference, closed platforms (like the MAKO system, Rosa Knee System, and Navio system) restrict the surgeon to specific, proprietary implant types. Finally, when switching to a traditional manual-jig approach, fully active robotic systems have been linked to higher soft tissue disturbance and technological challenges [21].

A systematic analysis of comparative studies was conducted to determine implant survivorship, complication rates, clinical outcomes, and radiographic outcomes in order to gain a broader understanding of the advantages of robotic-assisted total knee arthroplasty over traditional manual TKA [22].

4 **Benefits of Robotic Surgery**

Surgical time has decreased and efficiency has increased as a result of the improved evolution of the surgical workflow. In order to obtain the best possible mechanical alignment, implant sizing, and placement, surgical maps are computer-generated prior to surgery. The surgeon can mentally run through the process and examine and adjust the surgical plan before starting the procedure. Accuracy has increased and blood loss has decreased as a result of the robotic system's use [23].

More anatomically engineered joint implants and robotic tools are now accessible. Furthermore, custom-designed knee implants are now possible. Multiple technologies could be easily integrated into the operating room of the future to enable the surgeon to plan the surgery in advance, use a robotically guided cutting system to achieve high accuracy on bone cuts, and achieve optimal mechanical alignment with minimal back table instruments [24].

Numerous robotic surgical specialties have provided data that obese patients do not experience an increase in intraoperative or postoperative problems, conversion to laparotomy, or operative time when compared to the non-obese population [25,26]. Actually, in certain specialties, robotic surgery has been shown to take less time to operate on obese patients than open surgery, and compared to laparoscopic surgery, it has been shown to return bowel function and discharge home 24 hours faster, with similar operative time, blood loss, conversion rates, resection margins, and complications [27]. However, not all robotic treatments yield faster results; in fact, in bariatric surgery, the use of robotic vs laparoscopic techniques has been associated with longer operational times and lengths of stay [28].

When compared to open surgery, robotic surgery has been demonstrated to enhance outcomes for older patients, including shorter hospital stays, less medical and surgical problems, and faster discharge home. Despite longer operating periods, there may be fewer wound and fascial problems, as well as lower rates of blood loss and transfusions [29, 30, 31]. Remarkably, a number of studies conducted in a range of surgical specialties have revealed no variations in the results of robotic surgery between younger and older patient groups, suggesting that age is not a risk factor in and of itself. According to one study, early complication rates were much lower for older patients undergoing robotic surgery than for younger patients undergoing open surgery (17% vs. 59%) [32, 33].

4.1 **Operation time and robot planning time**

For the majority of investigations, it was unclear if the computation of total operating time included robot planning time. According to studies comparing a group of robots with a normal group, both groups operated for roughly one to two hours. Given the expense of robotic systems and the time commitment needed to train surgeons and other OR staff, the (unweighted) pooled saving of 21 minutes appears to be modest [34].

4.2 **Fluoroscopy time and frequency**

It is common to underestimate the radiation-related occupational health risk associated with orthopaedic trauma surgery [35]. According to the review's overall findings, robot-assisted surgery may help lower the overall radiation exposure for the patient and the surgeon. The surgeon must still be present at the operating table in order for the TiRobot to function. Papers discussing robotic systems that could be fully operated remotely were not found in this review, despite the fact that this capability may completely remove the surgeon's exposure to radiation.

4.3 **Screw placement accuracy**

Every study that looked at this result found that robot-assisted techniques resulted in more precise percutaneous screw placement. It is still unknown whether this increased precision has clinical significance, despite the fact that precise screw insertion is crucial for percutaneous fixation. However, one significant benefit of this method might be more precise screw placement. Sacroiliac screw insertion, for instance, is a quite unusual technique. With an abnormal screw placement, there is a chance of iatrogenic damage to neurovascular systems, making it a challenging surgery with a steep learning curve [36,37].

4.4 **Intraoperative blood loss**

In every study that used traditional surgery as a control group, the robot group experienced statistically substantially decreased intraoperative blood loss [38]. Both the control group (118 mL or less) and the robot-assisted surgery group (90 mL or less) experienced minimal intraoperative blood loss overall. The trial by Duan et al. revealed the largest reduction in intraoperative blood loss (32 mL), however this reduction is probably not clinically relevant [39].

4.5 **Postoperative physical performance and functional outcomes**

Although most studies were probably underpowered to identify meaningful differences, functional outcomes between robot-assisted operations and traditional surgery were comparable. After intramedullary nailing for intertrochanteric fractures, the robot-assisted group's Harris Hip Score increased by an average of 4 points, according to Lan et al. [40]. This statistically significant difference is not clinically relevant, nevertheless, because the Harris Hip Score has a least clinically substantial difference of 8 points [41].

4.6 **Fracture healing**

In the included investigations, fracture healing time was unaffected by robot-assisted surgery. According to the authors, there is little chance that using a robot has a major impact on fracture healing, and this finding might not be the most pertinent for further research [42].

4.7 **Strengths and limitations**

There are various restrictions on this study. First, only eight papers satisfied the inclusion requirements for this study because this is a relatively recent development in the field of traumatology. We were unable to conduct a meta-analysis due to the studies' heterogeneity, which made it challenging to clearly and succinctly explain the data. Second, Mandarin-language publications were not included. Several papers authored in Mandarin were identified by the authors. These papers were not available in full text and lacked an abstract in English. Selection bias may have resulted from this. Third, the included studies had a significant risk of bias and poor overall quality.

The uses of robot-assisted fracture fixation surgery in orthopaedic trauma surgery and its impact on surgical and patient outcomes are being described for the first time in a comprehensive study. According to this review, the clinical use of robot-assisted fracture fixation surgery has only lately become popular in traumatology and is currently limited to China. More significantly, this review pointed up the shortcomings and drawbacks of recent studies and offered suggestions for further research in this emerging area of orthopaedic trauma surgery [43,44].

5. Discussion

In traditional rigid robots, novel types of robots, instruments, and approaches have been developed for use in orthopedic surgeries [45]. For the purpose of core decompression of the femoral head osteonecrosis, a curved drilling technique was created by combining curved drilling instruments with a continuum dexterous manipulator (CDM) [46]. For minimally invasive orthopedic surgery procedures, cadaveric specimens have been used to test the curved drilling technique and flexible medical screws [47]. For the treatment of pelvic osteolysis and the autonomous debridement of osteolytic bone lesions in limited places, a redundant robotic system comprising a rigid-link robot and a CDM was suggested. For bone drilling in minimally invasive spine fusion, a miniature tendon-driven articulated surgical drill was created [48]. Additionally, handheld robotic devices for minimally invasive orthopaedic procedures have been created [49]. A concentric-tube steerable drilling robot was recently created for the purpose of implanting flexible pedicle screws and performing spinal fixation procedures [50]. Despite the fact that these innovative designs have not yet been used in a clinical context, orthopedic operations should soon profit from them. Both RS and CANS have been becoming more and more important in contemporary orthopedic procedures. The ratio of patents to articles pertaining to CANS and RS in knee arthroplasty rose from approximately 1:10 in 2004 to approximately 1:3 in 2014, per a review study [51]. Enhancing surgical procedures, tailoring surgical plans to individual patient profiles, and providing surgeons with intraoperative data and real-time viewing for a more accurate and precise surgical outcome are just a few of the advantages that RS and CANS offer [52].

Over the course of decades, RS and CANS have undergone significant upgrading and enhancement. In orthopaedics, RS and CANS will undoubtedly continue to flourish and be essential. The da Vinci surgical system is better suited for treatments involving soft tissues, but RS in orthopedics must be able to handle significant forces and stiffness because of the inflexible structure of its target item, which is bones. Increased implant location accuracy and precision, greater repeatability, increased implant stability, and decreased resultant discomfort are the primary benefits of RS in orthopedics. However, the primary drawbacks of RS include the possibility of safety issues, significant financial expenses, and possibly longer operating hours. The development of CANS will proceed in two concurrent directions. One is for standalone usage without RS, and the other is for integration with robotic systems. For the latter, CANS can be employed in more flexible procedures where robots are either not currently available or are not required. In that scenario, surgeons can execute standard procedures with the use of CANS, possibly leading to better and more precise surgical results [53].

The systematic review and meta-analysis comparing robot-assisted and traditional freehand approaches for pedicle screw insertion is based on RCTs and subgroup analysis according to the type of robot system employed, as per our understanding and literature search. The results of six earlier meta-analyses were as follows: According to one study [54], the robot-assisted approach can reduce the frequency of pertinent postoperative modifications brought on by screw malpositioning (16.7%). According to one study (16.7%), the robot-assisted method outperforms the traditional freehand method. For screw insertion, two studies (33.3%) [55] found that the accuracy rates of freehand and robot-assisted methods are comparable. One research (16.7%) [56] determined that, in terms of accuracy rate for pedicle screw insertion, the robot-assisted method did not outperform the traditional freehand method. According to one study (16.7%), the robot-assisted method is more accurate than the freehand method for placing pedicle screws. RCTs were the only trials included in these studies by Gao et al. [57]. The inclusion of both RCTs and cohort studies for meta-analysis in other research [58] might have led to less robust statistical findings. Eight RCTs were included in this study's meta-analysis. The Gertzbein-Robbins Classification was used in all chosen studies to define the accuracy of pedicle screw insertion [59]. For pedicle screw insertion accuracy utilizing Grade A, Grade A+B, and Grade C+D+E categories, the combined data showed no discernible difference between the robot-assisted and traditional freehand approaches. The clinical relevance of a misplaced pedicle screw in a postoperative patient who is asymptomatic is yet unknown, though. According to available data, not all misplaced pedicle screws lead to problems or the need for revision surgery. Neurological complications are not associated with a high risk of screw misplacement [60]. This could be because normal spinal architecture has an epidural "cushion" in the spinal canal, which allows for screw malposition error.

We carried out a subgroup analysis based on robot systems because of the substantial heterogeneity of the combined data. Numerous studies have demonstrated the benefits of Renaissance, another kind of tiny spine-mounted robot [61,62]. These systems consist of a controlling workstation and a little robot with a spine. Using CT images, surgeons ascertain the location and trajectory prior to surgery. Throughout the procedure, this robot is securely attached to the patient's spine. During the procedure, the robot supplies the trajectory and entry site for the instrumentation, and fluoroscopic images are taken and compared with preoperative CT scans. Now that the target vertebra can be precisely drilled or instrumented, surgeons can continue this procedure until all of the vertebrae have been found and instrumented [63,64]. The first orthopedic surgical robot created in China was called TiRobot. It combines an intraoperative 3D navigation system with a robotic arm that can track. The viability, safety, and accuracy of TiRobot guidance in spine surgery have not been well-supported by research [65,66]. The controlling workstation automatically imports the fluoroscopic pictures that are taken during operation. In addition to creating positioning commands for the robot arm, surgeons can design the surgical trajectory for screw placement, including the ideal location and size of the implants in the axial, coronal, and sagittal views. The arm completes the surgical trajectory by automatically locating and moving in response to commands from the controlling workstation. Following trajectory planning, a guide holder attached to the robot arm moves on its own initiative to the precise entrance point in accordance with the plan. Screws and guide pins can be inserted through the holder by the surgeon [67]. Six (86%) of the trials we included had operation time measurements [68,69]. According to this meta-analysis, compared to traditional freehand surgery, robot-assisted surgery required a much longer operating time. Ringel and associates. Longer operation times for robot-assisted surgery were reported by Tian et al., Kim et al., and Han et al. Hyun et al. [70], on the other hand, found no distinction between traditional freehand surgery and robot-assisted surgery. Techniques unique to the robot-assisted approach might make surgery more difficult for surgeons and take longer. Time may also be spent on tools that precisely guide the insertion of pedicle screws.

Both the patient and the surgeon may be exposed to a considerable amount of radiation during the procedure, particularly if the patient has anatomic landmarks or aberrant anatomical components. Because too much radiation can raise the risk of cancer, it's particularly critical to limit radiation exposure during surgery [71]. Two (25%) RCTs in our meta-analysis revealed radiation exposure times in seconds for each screw. Robot-assisted surgery was linked to a noticeably shorter radiation exposure duration than traditional freehand surgery. In conventional freehand surgery, the fluoroscopy duration per screw was almost four times longer than in robot-assisted surgery, according to Hyun et al. [72]. Nevertheless, they discovered that the total amount of radiation exposure during traditional freehand surgery is not appreciably longer than during robot-assisted surgery. On the other hand, robot-assisted surgery has a substantially lower cumulative radiation dosage. Because the surgeon left the operating room during the 3D imaging and the C-arm can be removed following the preoperation plan, limiting the surgeon's radiation exposure, the robot-assisted procedure can lessen the need for intraoperative fluoroscopy. Because there were so few trials in this investigation, the results showed a high degree of heterogeneity (I2=84%; P=0.01). Therefore, the statistical efficacy of these findings can be strengthened by including more high-quality studies. However, in general, the length of radiation exposure is related to the surgeon's clinical experience. As surgeons gain more experience, their radiation exposure may decrease. The majority of the RCTs we included were single-center trials with surgeons at varying training levels. There was no investigation of the surgeons' clinical background. [73] Malik et al.carried out a systematic review to investigate the relationship between radiation exposure in orthopedic surgery and the clinical experience of the surgeon. The comprehensive review comprised 18 papers assessing radiation exposure in orthopedic surgery, and the majority of the studies demonstrated that novice surgeons, including fellows and residents, had higher radiation exposures and longer total fluoroscopy times than more seasoned surgeons. Therefore, in order to perform a more comprehensive meta-analysis, future research should incorporate RCTs that address the clinical experience of surgeons [74,75,76].

The cost-effectiveness of those methods should be taken into account because robotic spine surgery devices come with significant extra expenses. The cost-effectiveness of robotic technology in spine surgery was examined by Menger et al. [77,78]. Based on the rate of revision surgery, post-surgical infection rate, duration of stay, and operative time, this study came to the conclusion that robotic surgery is a cost-effective technology. Despite being more costly than traditional spine surgery systems, robotic spine surgery systems have a reduced risk of postoperative complications, which lowers the overall cost of hospitalization. At a hospital that performed 557 elective spine procedures over the course of a year, robotic technology was estimated to have saved $608,546 [79,80].

There are several restrictions on our investigation. First, there weren't many RCTs. There should be more RCTs with bigger sample sizes. Renaissance was only utilized in three experiments, and TiRobot and SpineAssist were employed in two of them. According to our findings, distinct robot systems provide notably varied outcomes; therefore, additional research should be incorporated in each subgroup to increase statistical efficacy. Second, small sample sizes were used in the majority of RCTs [81].

6. Conclusion

This systematic review of comparative studies supports with fewer outliers and less mistakes in the coronal and sagittal planes, robotic-assisted orthopedic surgery provides advantages in accuracy, precision, and alignment correction, according to this systematic evaluation of comparative research. Better clinical results and higher patient satisfaction are observed in the early postoperative period. To confirm the link between increased accuracy and implant survivorship, complication rates, and functional results, more high-caliber long-term studies and RCTs contrasting contemporary robotic systems with traditional human approaches are required.

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