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Review Article

Robotic Surgery in Total Knee Replacement Surgery: Current Scenario and Future Perspective

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Abstract

Total knee arthroplasty (TKA) is an extremely promising procedure which re-establishes patient functionality and quality of life. Robotic arm assisted arthroplasty is gaining immense popularity in the field of Artificial Intelligence. This makes use of various technologies which is minimally invasive; wherein the robotic arm is promptly controlled by navigation technology. It also helps to fulfil a detailed preoperative plan, accurate implant selection, proper surgical sectioning of bone, and exact replacement of the artificial joint. These man-made joints portray high stability and accuracy. Substantiation of the use of robotics will improve the survival rate of the implant, functionality, and also the outcome which slowly gets accumulated as reported by the patient, nevertheless this has not been evidently verified until now. The application of Robotic TKA in present healthcare scenario has many limitations; firstly it is not budget-friendly and also leaves the patient with unnecessary exposure to radiation. The surgical efficiency is also compromised due to limited number of implant designs resulting in compatibility issues. The objective of this paper is to provide a neutral analysis of the available evidence or information regarding robotic technology for TKA.

Keywords: *Total Knee Arthroplasty (TKA); Artificial Intelligence; Robotic Surgery*

Introduction

Total knee arthroplasty (TKA) is a newly prominent and highly favourable procedure for patients having characteristically symptomatic last-stage knee injuries and lesions caused by various factors s for re-establishing the joint functions [1]. Most of the human physical activities require knee joints and also these are more easily prone for damages and accidents [2].

Current studies and research reveal that up to 20% of patients are unsatisfied with TKA irrespective of good implant material and the implant design chosen. In spite of well-established recovery rates, pre-operative usage of antibiotics or interventions used to prevent blood clots patient feedback is still compromised [3-9].

There are various factors that pose a threat to implant stability, post-operative functionality and long term implant durability. These factors include -Balanced flexion-extension gaps, accurate positioning of implant, safe guarding the periarticular soft tissue envelope and prompt ligament tensioning [10-17].

Although, the surgeons' technical levels affect the surgical procedures and design of prosthesis keeps improving, traditional knee arthroplasty and the frequency of eccentricity in artificial joint positioning and alignment is quiet great. The long term prevalence rate of the prosthesis is negatively compromised due to insufficient accuracy [1].

During the course of the surgical procedure the main reason of error is that it cannot rectify the inaccuracy caused by the operator's manual control. Direction finding and course plotting is significantly compromised in manual techniques. Hence in order to overcome the inaccuracy of manual plotting Robotic Surgeries came into existence [2].

Robotic technology finds its application in various clinical fields such as general surgery, orthopaedics, ophthalmology, cardiology, gynaecology to name a few; since this technology favours effective soft tissue dissection and good post-operative healing and rehabilitation. Over the past few decades robotic TKA has flourished immensely owing to its prompt and accurate implant placements and decrease in deviation in limb accommodation as compared to conventional jig-based TKA [1].

It utilizes a self-regulating device (usually a robotic arm) which can act together with the sensors and the domain objectively regulates the surgical instruments and prosthesis. It functions according to the direction-finding cues and planning preoperatively and refining the correctness of bone and prosthesis by accurately placing the operative tools. Converse to the real-time data, it can also identify the next operative step of the robotic arm, overcoming the faults occurring due to the manual control which greatly improves g the artificial intelligence and success of the surgery. It was in the year 1992 that robotic intervention marked its entry in the field of artificial intelligence [2].

Robotic arm-assisted joint arthroplasty through good navigation and control technology achieves correct preoperative drafting, accurate implant selection, minimally invasive surgery, perfect bone sectioning, and exact replacement by the artificial joint [2].

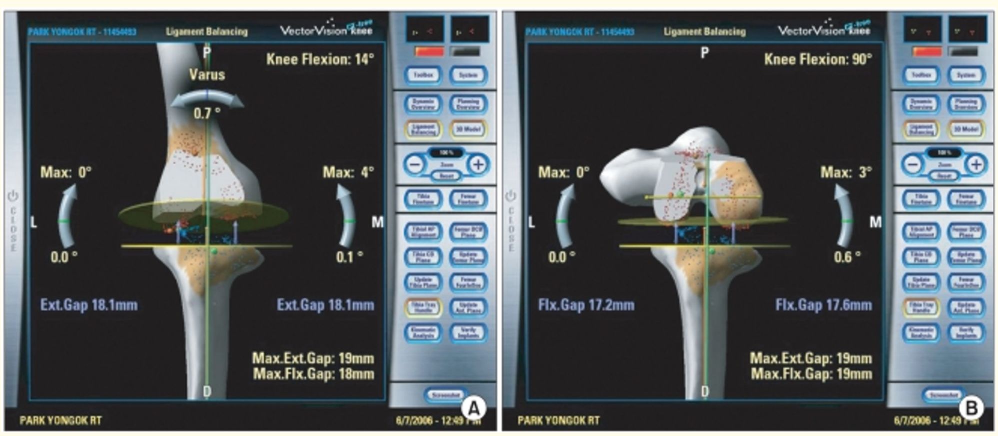

Figure 1: *Soft tissue balancing under navigation guide in total knee arthroplasty [13].*

Conventional jig based TKA limitations

In conventional jig based TKA bone resection and implant positioning requires efficient radiographic films taken prior the procedure; intraoperative anatomical landmarks and manually installed alignment jigs. Prompt skills and efficiency of the surgeon is of utmost importance in achieving an accurate implant position [18-22]. For the achievement of proper mediolateral ligamentous tensioning and balanced flexion-extension gaps is in need of a particular intraoperative gap valuation with restricted implant positioning and capability for customised bone sectioning. Intraoperative tightening equipment may help in providing guidance in soft tissue releases but there is frequent conflict between surgeons regarding the distraction force application and positioning of the joint [23-25].

To perform bone resection, it also uses a physically controlled saw blade and handheld instruments to safeguard the periarticular soft tissue envelope. Unintended injury to the surrounding ligamentous structures can occur due to manual technique for bone sectioning s; this compromises the clinical and functional repositioning after the surgical procedure, stability of the joint and long term survival rate [1].

The orientation response or thickness of the bone cuts cannot be determined by the previously mentioned information. The risk of blood clots and cardiorespiratory complications may escalate during the conventional jig-based TKA which uses the reference guides within the bone for sectioning [26-31].

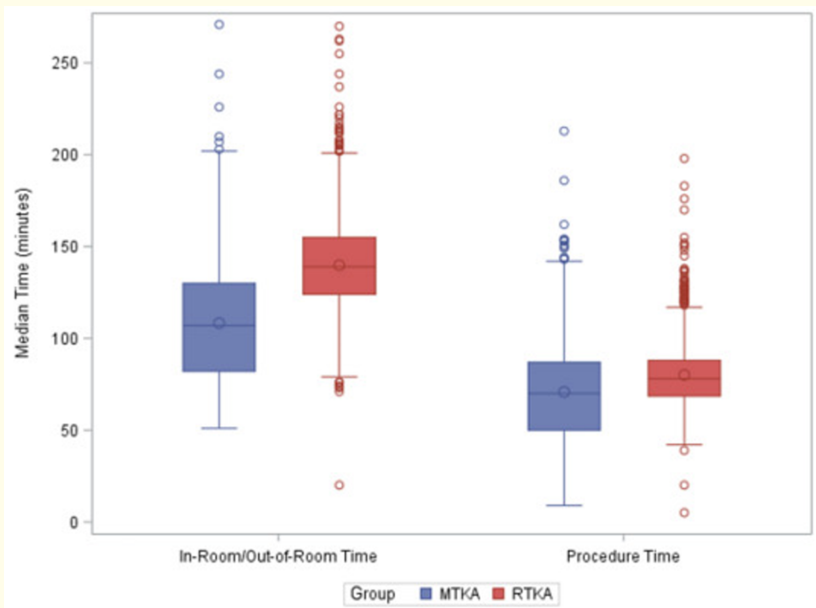

Figure 2: *Robotic versus manual total knee arthroplasty in high volume surgeons: a comparison of cost [32].*

Robotic TKA versus computer navigated TKA

Computer-negotiated TKA encompasses the use of computer systems that provide live on-screen evidences on patient's anatomical morphology and knee dynamics throughout the surgery. The bony anatomical structure of patient's knee joint is obtained by using intra-operative mapping of bony anatomical landmarks or preoperative CT scans (image-oriented navigation) on a generic model of the knee joint (non-image oriented navigation) [1].

By means of recommendations for bone sectioning and flawless implant positioning, patient-specific anatomical data is provided by computer navigation, wherein the computer application does not progressively restrict or confine the motor adequacy of the working surgeon. Computer applications are used by robotic TKA for converting anatomical information into a simulated patient-specific 3D representation of the knee joint. Hence this is used to calculate precise bone sectioning and implant positioning by the operating surgeon. An intraoperative robotic device aids in the execution of preoperative patient-specific design with increased level of accuracy. Robotic assistants are classified as fully active or semi-active systems based on the contingent amount of control the robotic device delivers the surgeons [1].

Semi-active versus fully active robotic TKA systems

Fully operative robotic applications work independently to achieve the strategic femoral and tibial bone resections. During the bone resection supervision, the surgeon may restore an emergency deactivation switch when needed. ROBODOC is a demonstration of a fully operative robotic TKA used. The surgeon performs the procedure of positioning the retractors (this is done to protect the surrounding soft tissues) and securing the limb into a fixed device. Later the robotic device executes the pre-planned bone resections [1].

There is a restricted acceptance of fully operative robotic TKA systems due to increased device setting up expenses and enlarged risk of complications during the knowledge phase. Of the 32 fully operative robotic devices Park and Lee [32] described few shortcomings which includes s patellar dislocation and ligament rupture, superficial infection, supracondylar fracture, patellar fracture, and common peroneal injury.

Semi-active robotic systems permit the surgeon in the maintenance of control over implant positioning and bone resection but limit the eccentricity from the preoperative surgical scenario. The Mako Robotic Arm Interactive Orthopaedic system (Stryker Ltd, Kalamazoo, MI, USA) is a very good example of image oriented semi- active system for robotic TKA. This robotic arm is tactile sensible with good visual and audio feedbacks that help the surgeon to modulate the direction and force of action of the saw blade within the margins of the femoral and tibial bone resection windows. Surrounded by a mobile leg holder boot, the patient's limb is fixed that can be established during bone resection for improving operative field. Jerking or uncontrolled movements disable the robotic device which leads to t iatrogenic soft tissue and bone injury. An imageless semi-operative robotic system uses a handheld stand to intra-operatively map bony anatomical features and guide bone resection which is devoid of the haptic confines is known as the Navio Surgical System (Smith and Nephew, Andover, Texas, USA). Recently, the Rosa Knee System (Zimmer-Biomet, Warsaw, Indiana, USA) has attained acceptance from the FDA. This system offers a computer oriented software program which converts 2D knee radiographs into a 3D individualized osseous model. Computer-oriented ideas on ligament balancing and implant positioning are formed before execution of the customised plan that is desired using the robotically situated cutting blocks [1].

Robotic arm-assisted knee arthroplasty

Development process of robotic arm-equipped unicompartmental knee arthroplasty (UKA)/Total knee arthroplasty (TKA)

The technology of robot-equipped system is estimated to achieve compatible surgical results and confound knee joint replacement in a sparsely invasive environment by different surgeons. The first active robots used were CASPAR and ROBODOC in TKA. The first generation of joint robots that were used in TKA were Active Robots. These lacked auto-correction efficiency, were unskilful and tough to relate during surgery. It also triggered obstacles associated to surgical instruments, and the surgical consequence was not improved than traditional methods. Semi-active robot was established for this purpose. ACROBOT Robot was a widely used system in Europe. In North America, MAKO and NAVIO surgical robots were approved by the US FDA. Semi-active robots are a new genesis of robotic arms with good tactile perception. These have somewhat ruled out the shortcomings of the previous generation, enabling the surgeon a strong control over the robot which in turn promptly avoids the slip-ups in intricate lesion areas and generation of ' accurate robotic navigation and fine cutting. This semi-operative system can evade inaccuracy of the surgeon's osteotomy through auditory, visual and tactile feedback. Thus, it suggestively progresses the effectiveness of the surgical robot, attain a more exact calibration, and successively achieve the preoperative predictability during the operation.

Chin., *et al*. [33] depicts that robot-equipped TKA and UKA are directed to improvise the results radiologically, with minimal alterations in the mid and long-term outcomes which functionally assimilated with conventional methods through meta-analysis and systematic review on a total of 23 studies embracing 2765 knees. Kayani., *et al*. [34] assessed the early functional recuperation and hospital discharge time prospectively. Thus, they found out in their study that there was a speedy early functional recovery time in the robot-equipped operation and also reduced the hospital stay as compared to conventional jig-based TKA.

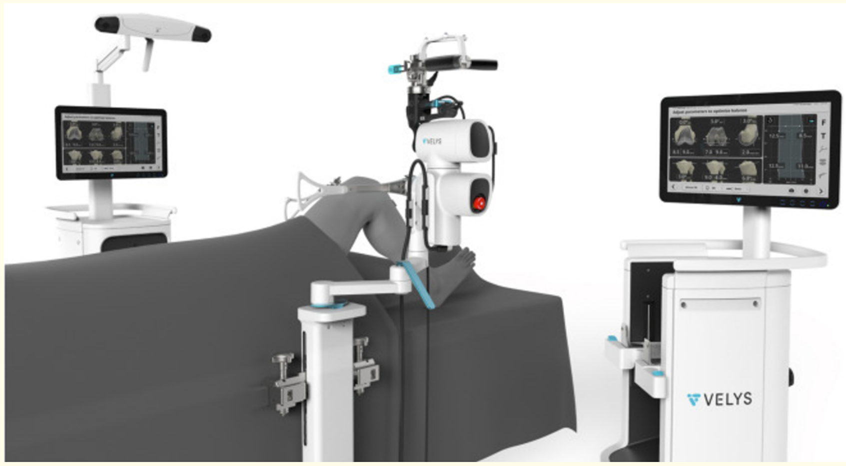

Figure 3: *Robotic arm assisted total knee arthroplasty [35].*

Efficacy of robotic arm-equipped knee arthroplasty

Surgical robots are locked systems hence at present they cannot be utilised globally. Used knee prosthesis can be followed from the same robotic company. Therefore, the same type of knee joint replacements cannot be made useful for comparison and evaluation of different robotic systems.

Clinical efficacy of robotic arm-equipped TKA

Till date there is insufficient clinical data accessible for robotic arm assisted TKA procedure. ROBODOC, being an active robotic system yields an immense mid-term follow-up outcome. Clinical studies on the semi-functional system RIO are exceptional and are different from *in vitro* experimental studies. The range of motion for TKA has experienced negligible transformations between robot-assisted and conventional knee arthroplasty [35].

According to a study by Kayani., *et al*. [36] the total surgical time is prolonged yet the functional recovery is at a greater pace with reduced hospital stay duration a as compared with conventional jig-based TKA.

Marchand., *et al*. [37] used the robotic technology before and after the surgical procedure to compare the alignments of 330 cases. Patients with not more than 7 alignment deformities y were completely rectified; while 96% of those alignment deformities were within the range of 3 and resumed to normalcy after surgery.

Suero., *et al*. [38] compared robotic TKA with conventional TKA with approximately 30 and 64 cases respectively, and found that the degree of discrepancy in the robotic group was crucially lesser than in the conventional group, but the replicability was higher notably.

Moon., *et al*. [39] described the consequences of alignment postoperatively, a collation study using the active robot ROBODOC along with conventional equipment and found no notable difference in the alignments of the lower limbs, but noticed a difference in the precision of the rotation of femoral prosthesis.

Song., *et al*. [40] surveyed 30 patients with a history of bilateral TKA during the same period, with one side receiving robotic surgery and the contralateral side conventional surgery. When the results of 1 year follow- up was evaluated there was no significant difference in functional score and knee mobility between the two groups but the radiographic images depicted more precision in calibrations in the coronal and sagittal planes of the robotic group.

Siebert., *et al*. [41] analysed retrospectively case studies of robotic surgery and conventional surgical procedures of 70 and 50 cases respectively, and initiated that robotic surgery reduces the prevalence of unfavourable events and soft tissue swelling after the procedure. Sultan., *et al*. [42] recommended through literature review that robotic TKA is more advanced than conventional surgery.

Marchand., *et al*. [43] used the McMaster Universities and Western Ontario Osteoarthritis Index for investigating the patients' contentment 6 months postoperatively. Among those patients 20 each received conventional surgery and robotic surgical procedures respectively. Later it was noted that patients who underwent robotic surgery had lower pain score and higher contentment scores postoperatively; furthermore these patients also exhibited good functionality score.

Liow., *et al*. [44] conducted an arbitrarily controlled study by applying "SF36" quality of life scoring system for assessing the robotic surgery and conventional surgery cases, 31 and 29 respectively. The results depicted that the robotic group exhibited high quality of life score as compared to the conventional group. In one of his uncontrolled study, Kim., *et al*. [45] trailed 32 cases of robotic TKA and found a significant increase in the postoperative knee society score.

Robotic TKA learning curve

The robotic TKA learning curve is vital for accepting the impact of this procedure on the surgical plan, setting up theatre lists and operative cases, and finding any additional complications or threats while procuring the surgical ability. Kayani., *et al*. [46] determined the robotic TKA learning curve by evaluating radiological and operative markers of the curve in 60 successive conventional TKAs followed by robotic TKAs. By using the collective accumulative exploration, they reported that the learning curve for surgical team and operative time provided a significant increase in assurance levels with robotic TKA in 7 cases. It was observed that robotic TKA had no learning curve effect for accomplishing the designed tibial and femoral implant arrangement, posterior condylar offset ratio, limb adjustment and native joint rehabilitation.

Sodhi., *et al*. [47] explored the robotic TKA learning curve in two different surgeries and found an increase in operative time in initial 20 robotic TKA cases. Later in both the surgical procedures the operative period in robotic TKA was parallel s to those of conventional TKA. The robotic TKA procedure exhibits a more streamlined technique than the conventional jig-based TKA by diminishing the need of instrument trays, cutting blocks and calibrating guides. This automatically reduces the need for trailing and enabling more rapid computer-lead bone resections, due to a significant accuracy of preoperative surgical plan. Nevertheless, current studies show that in the robotic TKA learning phase the surgical time is reduced thereby enhancing the efficiency phase for robotic TKA [46,47].

Existing problems

Prolonged operation time

For new skills, numerous of them might face unmanageable challenge with regards to the lengthening of surgical time during the promotion period. Surgeons recurrently need a definite time for overcoming the learning curve, which leads to prolonged surgical time at this stage. Providentially, the learning curve yields a relatively flat curve in robotic UKA, so after being trained even young surgeons with minimal experience can complete the task. A survey of 11 surgeons was conducted which revealed that to complete the learning curve; UKA surgical robot requires an average of 8 surgeries; wherein a stable surgical time is observed [48].

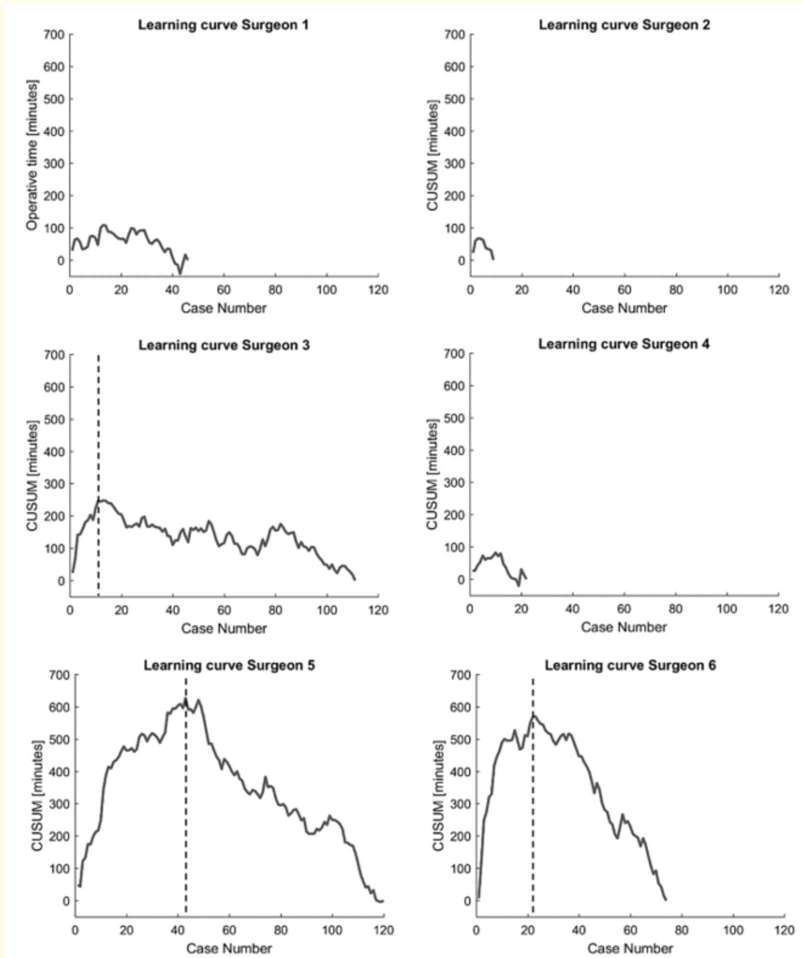

Figure 3: *Robotic arm assisted total knee arthroplasty [35].*

Complications of robotic surgery

Robotic surgical procedure for osteotomy makes use of drills in place of sharp tools such as oscillating saw, thus reducing the injuries to the cruciate ligaments and collateral ligaments. Robotic UKA requires insertion of the optical target on the bone; wherein the regular fixation nail diameter should be 3 mm or more in order to avoid intra-operative micro movements and embrace a thread design. The frequency of lower limb fractures is accelerated when the fixation holes are made in the femur and tibia, and stress application takes place around the hole. Additionally, it is noted that the healing process is significantly compromised at the fixation of optical target [2].

Conclusion

Referring to the already existing studies, the benefits of the robotic group lie more in the accurate calibration and positioning of prosthesis as compared to its clinical score. Anticipated randomized controlled studies with longer follow-ups and larger sample size are required to study its opportunities and obstacles. There has been an enormous unceasing progress in Artificial Intelligence and Robotic technology which enables to successfully perform TKA. Robotic arm-assisted arthroplasty will soon become a reliable technique.

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