Industrial Engineering Journal
ISSN: 0970-2555
Volume : 52, Issue 2, No. 1, February : 2023

USE OF ARTIFICIAL INTELLIGENCE IN KNEE REPLACEMENT SURGERY

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Abstract
Joint replacement is widespread throughout the world and is considered a particularly effective treatment for various hip and knee pathologies in patients of all ages. This is also why an increase of total hip replacement (THA) and total knee replacement (PTG) has been observed over time, which is expected to increase significantly in the next decades. In the last decade, there has also been a growing interest in rapid hospitalizations characterized by a shorter stay and a faster functional recovery for the patient undergoing total hip and knee replacement surgery. The fast-track journey is characterized by an optimized or accelerated perioperative progression compared to a standard surgical procedure. A fast-track journey aims at reducing perioperative morbidity, physiologically optimize anesthesiological procedures, optimize pain management and aggressive mobilization. Artificial intelligence can allow an accurate selection of patients eligible for a fast-track journey in prosthetic surgery. In this way it would be possible to reduce the duration of post-surgical hospital stay, guaranteeing the patient an appropriate functional recovery without increasing the risk of complications.

Key Words: arthroplasty, knee replacement, precision, recovery, robotics, surgery

Introduction
From SIRI to self-driving cars, artificial intelligence (AI) is progressing rapidly. Robotics has also assumed an important role in medicine and healthcare. Orthopedic surgery began to incorporate robotic technology in 1992, with the ROBODOC system's introduction for total hip replacement. The current Mako robotic system used today benefits joint replacements and hip and knee arthroplasty with excellent results. It limits blood loss, reduces operation time, and achieves limb alignment. Artificial intelligence may help orthopedic surgeons predict patient outcomes following joint replacement surgery, an exciting prospect for both patient and surgeon.

Artificial Intelligence shows promise in joint replacement surgery by:
1. Promoting practice efficiency
2. Personalizing patient care
3. Improving precision and accuracy
4. Expanding high-quality orthopedic care to lower resource settings
5. Allowing smaller incisions to promote faster healing times

6. AI-assisted robotic procedures can result in 5 times fewer complications than traditional surgery.

Robotics are improving the way doctors do surgery, including joint replacements. The physician controls the robotics, allowing the surgeon to combine their knowledge and judgment with the precision and control of a robot. Hip replacements with robotic technology in particular, can be four times more accurate and reproducible than conventional hip replacements. This accuracy helps spare healthy bone and tissue while getting rid of diseased and problematic bone and tissue. Artificial intelligence can be used more efficiently in surgical decision-making and eliminate risk factors and human-driven errors.

The medical imaging information system allows only preoperative measurements of all angles but does not simulate the intraoperative knee osteotomy and the post-osteotomy prosthesis placement. In TKA, according to the isometric osteotomy method, the specific thickness of the osteotomy also affects the choice of the size of the prosthesis. The accuracy of the digital planning software in predicting the size of tibial prosthesis has been reported to be as low as 63%, and that in predicting the size of femoral prosthesis is 69%. Schotanus et al. similarly concluded that the outcome of digital preoperative planning was yet to be determined.

In the field of orthopaedic surgery, digital technology has made it possible to digitally simulate surgery. The CT scan of the patient's knee joint, with a slice thickness of 1 mm, is obtained in the DICOM format, and the obtained data are input into the corresponding digital software to reconstruct a three-dimensional (3D) bony model of the knee joint. Further, calibrated weight-bearing full-length AP and lateral radiographs of the lower limb are taken, and the statistical shape model (SSM) technique is used to derive the 3D model of the knee joint. The 3D model is then automatically aligned with the CT-reconstructed bony 3D model of the knee joint to obtain a 3D spatial model of the knee joint and the full-length of bilateral lower limbs. After scanning all models of the selected prosthesis, the installation and alignment of the prosthesis are simulated on the 3D model using the measured joint lines and angles. The application of such digital simulation technology in the preoperative measurement of TKA has enabled the lower extremity joint line measurement and osteotomy and prosthesis installation to be more accurate, which is a great leap forward in joint surgery measurement technology. It has been confirmed that the deviation of the SSM technique in fitting the knee joint is less than 0.2–0.4 mm, which can meet the rigorous standards required for clinical application.

Notably, the development of novel computer navigation systems has risen markedly in recent years. The new computer navigation system, Knee 3 software, from Brainlab, Germany, was launched in China in 2020. The system comes with the advantage of simple and fast registration. It enables intraoperative visualization of osteotomy positioning and dynamic real-time display of knee flexion and extension gaps throughout the procedure, which helps the surgeon create individualized lower extremity alignment and soft tissue balance in patients. Compared with conventional computer navigation systems, Knee 3 software not only ensures accurate osteotomy but also improves the soft tissue balance in the knee joint. The Knee 3 system provides real-time intraoperative display of the joint gap in the form of gap values and gap graphs, allowing the operator to visually assess the knee flexion and extension gap balance. When planning the surgery, the surgeon can adjust the angle and position of the femoral and tibial osteotomy according to the patient's lower extremity joint lines, and the system can also display the impact of the corresponding osteotomy changes on the joint space in real time.

The disadvantage of the Knee 3 system is that it includes system setup, tracker fixation, and registration steps. Moreover, since the Knee 3 software dynamically displays the lower limb joints line and knee gap information in real time, the operator needs to quickly interpret the relevant information and devise a suitable surgical plan, which increases the operation time. In addition, because computer navigation-assisted surgery requires the installation of fixation pins to fix the tracker, there is a risk of fracture. Smith et al.reported that during computer navigation system-assisted and robot-assisted TKA, the incidence of fractures related to fixation pins was 0.06%–4.8%, and most of the fractures occurred in the femoral shaft. In recent years, AI deep learning technology has been successfully applied in the field of medical image processing, realizing automatic recognition and segmentation of the lesion or target area, and with high accuracy.

AI deep learning technology was applied to independently build neural network PointRend_ Unet on the basis of ensuring the accuracy and robustness of segmentation, which realizes the fast segmentation of knee joint CT image data to improve the work efficiency and reduce the preparation cost. The segmentation results obtained by clinical evaluation are satisfactory, and the steps are as follows: First, establish a CT image database, import a large number of knee joint CT images of patients into Mimics software (Materialise Company-Technologielaan 15, Heverlee, Leuven, Flemish, Belgium), reconstruct the bone structure according to the bone threshold setting on the basis of the threshold method, select the target bone structure, and then conduct threshold growth segmentation; then, conduct manual trimming, and finally, save the data in mask format. Secondly, the neural network is built and trained. Through the segmentation of the neural network, the knee joint CT image data form the femur, tibia, fibula, and patella regions, respectively.

Finally, the visualization of the target bone structure 3D model is generated through 3D reconstruction technology. Although non-imaging mode and ultrasound and other non-radiation exposure technologies are emerging, the new TKA auxiliary technology commonly used in clinical practice is based mainly on CT images, which extract the three-dimensional anatomical model of the knee joint from the patient's CT images for subsequent surgical planning. The manual processing of CT image data is time-consuming and laborious. The realization of simplified, automatic, and accurate segmentation of knee joint CT image is the key to the wide range clinical application of TKA new auxiliary technology. The development of artificial intelligence technology has led to the development and research of a large number of medical image automatic segmentation systems. The commonly used neural networks are deeplab or Unet. These methods have effectively improved the stability of automatic segmentation and the efficiency of the treatment plan workflow.

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