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Patient specific instrumentation: A minimally invasive technique for knee arthroplasty

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Abstract

Patient specific instrumentation (PSI) is considered a minimally invasive technique regardless of whether the skin incision is small or traditionally long. PSI provides two pieces of instruments to replace the complex conventional instruments that may reach up to 100 pieces. PSI eliminates the need for using the invasive intramedullary rods that perforate the medullary canal leading to higher risk of bleeding, fat embolism, infection and fractures. PSI also reduces operative time and speeds the recovery of patients. In this review, the authors collect the data given on total knee arthroplasty (TKA) using PSI. The criteria for TKA as well as the development of different surgical techniques and how PSI would benefit the surgeons and patients to conduct a successful surgery have been discussed. (El Med J 2:4; 2014)

Keywords: Patient Specific Instrumentation, Total Knee Arthroplasty, Minimally Invasive

Introduction

Total knee arthroplasty (TKA) is an effective method in the treatment of severe osteoarthritis of the knee joint. TKA aims to restore neutral limb alignment and establish adequate soft tissue balance. Malalignment may lead to pain, stiffness, instability, wear, osteolysis and increased risk of loosening. The aim of the surgery is to make proximal tibial and distal femoral bone cuts at 90 degrees to their respective mechanical axis [1].

TKA is considered one of the most successful orthopedic procedures, and since its introduction in 1960, much effort has been paid for improving the designing of the implants, standardization of surgical techniques, fixation methods, and infection prevention measures [2, 3]. Survival rate after TKA for old age group (>60 years old) has been determined to be as high as 85-95% in 10-20 years, as opposed to young, active and obese patients as well as cases difficult for revision [4-14].

Computer-assisted orthopedic surgery (CAOS) is an enabling technology that has the ability to improve accuracy and reproducibility of TKA surgical techniques. CAOS aims to provide the best option for TKA based on perfect preoperative picture which accurately shows the position of the center of the joint in order to provide even alignment and perfect level of bone cuts. It also aims at avoiding intramedullary perforation and solving the problem of in-between sizes. CAOS thus decreases the number of instruments and, in turn, the cost effectiveness and operative time [15]. Moreover, with computer assistance, even unexperienced surgeons are able to get better alignment immediately and constantly [16]. Improved alignment has led to better survival rates and clinical results. Merloz et al found that nearly 40-50% of revision knees could be prevented if perfect alignment and perfect ligament balancing is ensured [17].

Criteria for TKA

In TKA, the location and angle of insertion of femoral intramedullary rod are very important and account for coronal and sagittal orientation of femoral component [18-20]. Minor changes in location of entry point of intramedullary rod increase the chances of malalignment and put the knee in the category of "outlier". The intramedullary rod can lead to malalignment if its insertion angle and its position in canal are not accurate [21-23]. Opening the medullary canal also predisposes the surgical subject to more bleeding, more chances of infection and embolism and chance of fracture [24-26]. The rotational orientation of femoral component can be determined by the palpable axes within the knee joint (mainly epicondylar and posterior condylar axes). The transepicondylar axis is less predictable and significantly more externally rotated than the anteroposterior axis [23, 27, 28]. The femoral component sizing is not fully proven [29]. The stylus of the anterior referencing systems has the limitations that it may lead to posterior placement of stylus or possible undersizing [27]. A study by Parratte et al concluded that postoperative mechanical axis does not affect the 15-year survivorship of implants [30].

Another problem that may risk notching or decrease the space between the posterior coronal cut on the distal femur and the transverse cut on proximal tibia (flexion gap) is the "in-between sizes." Navigated TKA can oversize femur. In the conventional instrumentation system, the femoral sagittal cut angulation is determined by the position of intramedullary rod being in certain degrees of flexion to mechanical axis. In navigated TKA, this cut is at 90 degrees to the mechanical axis (placing the femoral component in extension) in comparison to conventional technique. The femur gets oversized because of this relative extension and to prevent notching (particularly in curved femurs). The inner surface of the anterior part of femoral implant should lie flushed with the anterior cortex, replicating the patient's anatomy [27, 31].

Surgical factors are very important for the long-term durability of implants [32-35]. The tendency to leave the knee in slight flexion or to put femoral component in internal rotation has been noticed. Minor errors in bone cuts cannot be visualized in conventional technique [36]. The fiddle factor, the assembly, disassembly and sterilization of several tools might affect the accuracy of bone cuts and put the patient under the risk of contamination [37].

Patient specific instrumentation

Patient specific instrumentation (PSI) is a new concept that develops different aspects of computer assisted technologies to perform vir-

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tual surgery and produce patient specific instruments based on preoperative imaging. It does not have the drawbacks of navigation and robotics, such as high cost and complexity.

Cost, operative time, alignment and number of outliers are all questionable; they might vary according to each orthopedic teamwork results. Cost is a perceived barrier to using the custom-fit positioning technique, and Mont et al have found that surgeons who use this technique have reduced procedure time [38]. A prospective, randomized trial by Hamilton et al has shown that PSI did not shorten surgical time or improve alignment, compared with the conventional technique, but reduced the required number of trays [39].

In addition to the time of the theatre (that has economic implications too), the navigation systems are costly, need training and have a learning curve. Experienced surgeons complain of not getting the "feel of the knee" [40]. In terms of the cost factor, a few surgeons have suggested to utilize navigation-system-equipped orthopedic hospitals as referral hospitals, where complicated cases can be referred [41, 42]. PSI exploits the accuracy of computer and matches the patient's anatomy. It decreases the surgical time and soft tissue dissection (which makes simultaneous bilateral TKA safer) and is proven affordable too [43].

In an experimental study by Hafez et al, a number of 45 TKA (29 plastic and 16 cadaveric knees) were performed using PSI without conventional instrumentations, intramedullary perforation, tracking nor registration [44]. The study revealed mean errors for alignment and bone resection within 1.7° and 0.8 mm (maximum, 2.3° and 1.2 mm, respectively) [1].

PSI requires a CT scan or MRI of the patient's knee (in addition to the routine X-rays). Ensini et al treated 25 patients with a CT-based PSI system and other 25 patients with an MRI/X-ray-based system, and both PSI systems showed good alignment in the coronal plane in all stages. However, for a few measurements, a better performance was observed in the MRI/X-ray-based system than in the CT-based system [45]. However, MRI has been shown to provide a suboptimal accuracy and inferior quality 3D image of the knee. White et al have found that the 3D bone models generated from MRI were dimensionally less accurate and visibly inferior in comparison to CT-based 3D models [46]. The external surfaces of MRI models were rough because of soft tissue structures which could not be removed by the threshold. The technique of segmentation (removal of soft tissues) of an MRI data is difficult, time consuming, subjective and imperfect. In fact, many research works have focused on improving segmentation of MRI-based data [47].

The preoperative planning for a technique of PSI for TKA includes sizing, alignment and bone cutting based on imaging and then designing and producing femoral and tibial templates that act as cutting blocks (Figure 1).

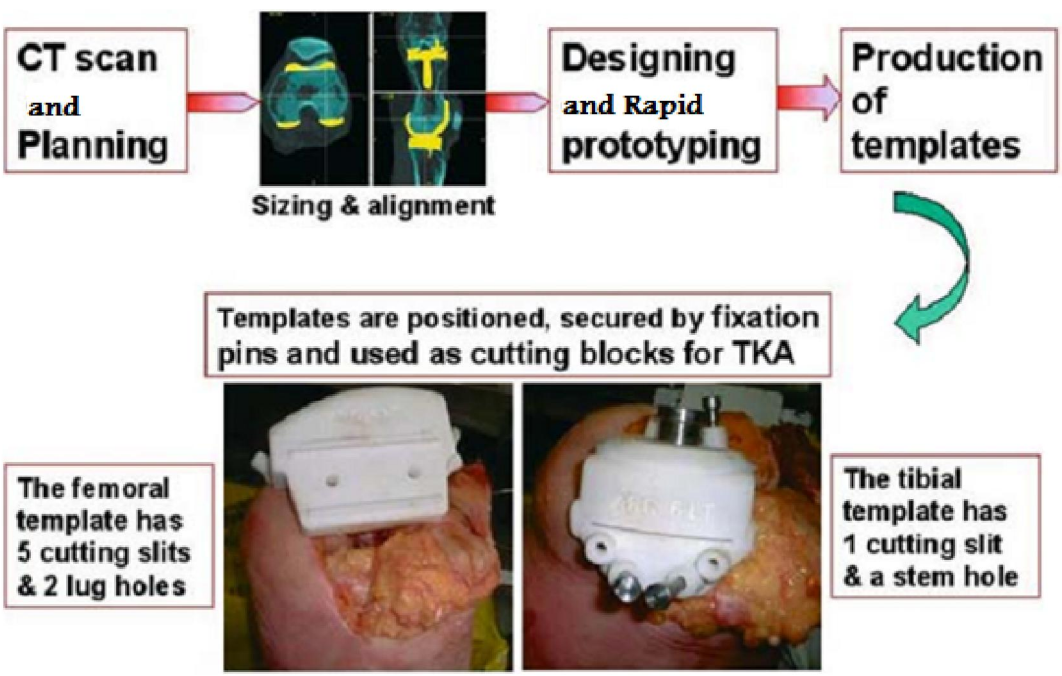

Figure 1: Patient specific instrumentation technique.

Majority of the conventional jigs (navigation system is also based on these jigs) is based on the Caucasian anatomy. Fitting a different-size implant to an individual requires either cutting the implant, bone or soft tissue, which increases the role of surgeon in pain management and infection control [48]. The main idea of PSI is that knee-joint arthroplasty procedures can be individualized, with benefits including precise realignment of the normal mechanical axis of the operated lower limb, minimized resection of the patient's bony tissue, reduced surgical time, simplified instrumentation, reduced perioperative and postoperative blood loss, no need of femoral medullary cavity reaming and reduced rate of thromboembolic complications.

The custom-fit TKA is designed to recreate the natural prearthritic alignment of the patient's knee with the goal of increasing function.

Individuals who undergo custom-fit placement show better stability and postoperative mechanical axis alignment and also possess acceptable clinical outcome at three months. The consistent sizing of the implants, secure fit of the femoral and tibial guides, short operative duration, low transfusion rate and lack of fat emboli support continued use of the custom-fit technique [49-51].

Walker et al found that while newer technologies can offer further improvement in total knee systems, implementation will be strongly affected by the need to satisfy the competing requirements [52]. However, Boonen et al compared patient specific to intramedullary-aligned TKA and found that the fraction of outliers for patient specific TKA was relatively higher, although it has proven better accuracy, lower blood loss rate and shorter operating time [53].

Roh et al assessed the precision and reliability of patient specific TKA in comparison with the conventional technique. They concluded that the accuracy was comparable between 2 patients' groups (outliers in hip-knee-ankle angle was 12% in the PSI group and 10% in the conventional instrument group) whereas sagittal alignment and femoral component rotation did not differ in terms of outliers. Moreover, they reported that the PSI procedures have been aborted frequently, incurring expenses that did not benefit patients [54].

Another comparison between the conventional and patient specific TKA procedures shows that PSI technology is superior to conventional instrumentation in achieving a neutral mechanical axis following TKA, but it needs further follow-up to ascertain the long-term impact of these findings [55]. PSI allows the optimum balance of technology and conventional surgery by reducing the complexity of conventional alignment and sizing tools. Thus, the advantages of accuracy and precision claimed by computer navigation techniques are achieved without the disadvantages of additional intraoperative inventory, new skills, or surgical time [56].

Although this technique could be used for routine primary knee, another study has shown the clinical application for a few absolute indications of PSI (e.g., old malunited distal femur supracondylar osteotomies, ASA grade 3-4 patients where time of surgery is important and hemophilic arthropathy where intramedullary jigs have to be avoided and surgery time has to be decreased) [44].

PSI system enables less number of instrumentations and less stress during surgery. It can benefit the hospital by improving operating room time efficiencies by shorter setup time and eliminating the cleaning, sterilization and inventory costs [57]. It will definitely improve ergonomics at work place and might prevent burn-out of the orthopedic surgeons (as it relieves the clinician from multiple intraoperative decisions), particularly when a recent economic model has predicted a supply side crisis [58-60].

PSI has an additional benefit on surgical teaching. Trainees can learn preoperative planning on software and order the manufacturer to make a virtual bone model. Simulation can play an important role for the training surgeons [61]. The surgeons can use PSI as pin locators and can check the intraoperative accuracy of these locators before making the bone cuts.

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