How has Computer-Navigation changed TKR?

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Introduction

Since the design of the first total condylar knee replacement in 1974, knee arthroplasty surgery has remained one of the most successful procedures in orthopedics. Despite the procedure gaining good 90% long-term follow-up [1–2], there remains a large number (20–40%) of patients who are dissatisfied with the procedure [3–5]. This may be related to patello-femoral pain, medial impingement, instability, increased wear or early failure. A number of studies [6–11] have highlighted the incidence of patello-femoral complications and its relationship to femoral component mal-rotation [12–15]. Polyethylene wear is multifactorial; however, it is accepted that more then 3° of mal-alignment in a coronal plane will lead to differing loading patterns on the tibial polyethylene inserts, and more wear [16, 17]. No thought has yet been given to combinations of mal-alignment, e.g. varus, internal rotation and flexion of the femoral component and in a large series [18] of 212 consecutive TKR revisions, 25% of patients had significant polyethylene wear. Instability of the primary TKR remains a leading cause of revision – with an incidence of 21% in early revisions, whilst overt mal-alignment of the components was present in 11% of revision cases [18].

A number of series have reported on the interval between the index operation and the revision procedure. Fehring et al. [19] showed that 64% of all revision cases where performed within 5 years of the index procedure. Almost 22,000 knee revisions were performed in the USA in 1999 at a cost of $ 262 dollars [20] and the numbers of revisions are rising.

It is clear that the numbers of dissatisfied patients and revisions are rising and the reasons are multifactorial. However, the accuracy of bone resection and implantation together with good soft-tissue balancing clearly play an important role. Since the introduction of standardized knee instrumentation, very little has changed and many implant companies still produce rigid IM/EM rods to which cutting blocks are attached. These instruments are based on normalative anatomical studies which allow some surgeon input in the coronal positioning (varus/valgus) of cutting blocks but even less input in the sagittal positioning (flexion/extension). Many instrument systems still use fixed posterior referencing cutting blocks to determine femoral rotation, which produce mal-rotation by not taking into account posterior condylar wear [21]. Thus a number of errors can be produced which may ultimately lead to premature failure of the total joint inserted. Petersen and Engh [22] reported on post-operative radiography following conventional arthroplasty, 26% (13/50) failed to achieve alignment within 3° of varus or valgus.

Computer-assisted TKR was introduced with the aims of improving component alignment in the coronal, sagittal and axial planes consistently and thus narrowing the “bell curve” of distribution for any individual surgeons results. It logically follows that better kinematics and wear patterns should follow if this is achieved as opposed to a mal-positioned implant. By allowing the surgeon to dynamically assess deformity prior to bone resections, navigation systems allow the surgeon to carefully calculate which soft tissues will ultimately be released, to give the perfectly balanced knee. The ability to immediately assess the effects of any release on kinematics, gives instant biofeedback to the surgeon on which further decisions can be made. One major additional advantage to navigation systems is that the majority now use instrumentation that is entirely extra-medullary, thus reducing the risk of fat embolism.
Overview of Computer-Assisted Systems

All navigation systems have a core of components that comprise a computer, an optical system, mobile trackers (either infra-red or passive reflectors), insertion pins and a working tool that may be hand-held or pedal-operated. In all systems, the computer receives information from an infra-red camera array. The cameras track the signals, which come in from the working area via trackers, which can be active, when they generate the infra-red signal, or passive if they reflect the infra-red radiation, which comes from the source. These trackers can be fixed to the patient and therefore indicate fixed anatomy, or they can be mobile. Mobile beacons can act as pointers or can be attached to specific instruments which the computer can recognize. The progress of an instrument can therefore be followed in its relationship to the anatomy.

Picard [23] first suggested that navigation systems be divided into those that require pre-operative information (CT or MRI scan) to be collected and those where intra-operative information is gathered during surgery. This latter group is further subdivided into two groups of systems. The first is those which use pre-operative imaging, in which usually a fluoroscopic picture is taken and the data transferred directly to the computer through a hard-wire connection. The second is image-free systems, which use an anatomical model embedded in the computer memory, which is upgraded by a process of the surgeon picking anatomical landmarks on the knee during surgery. This itself can be either through geometric mapping or true bone morphing.

Navigation systems require a registration process irrespective of what type of system is being used. The process can take between 7 and 30 min, depending on what system is being used and the experience of the surgeon. Registration requires the surgeon to input key data into the computer using anatomical landmarks in the limb. Thus the center of the femoral head is determined most often by some form of kinematic analysis, whilst the surfaces of the distal femur and proximal tibia can be mapped directly as can key rotation landmarks, which will affect both femoral and tibial rotation. Key-ankle landmarks are mapped directly, thus together with the center of the femoral head, center of distal femur and proximal tibia gives both the anatomical and mechanical axes of the limb. The accuracy of the registration process is fundamental, as although averaging algorithms are used, a poorly performed registration will result in a down-grading of the overall accuracy.

Another feature of importance to surgeons is how "captured" the surgeon is by the system. In closed platform systems the surgeon is often restricted to one particular type of knee arthroplasty with one particular program. More programs increase the surgical freedom to choose between implants but also considerably increases the cost of systems. Closed systems will also often not allow the surgeon to progress unless specific data is acquired – which is often not necessary. Open platform systems allow surgeons to input a key data set of information and then proceed as the surgeon wishes. There is no restriction on choice of component or indeed primary, revision or unicompartmental procedure.

Review of Clinical Results

Chauhan et al. [24] produced one of the first randomized controlled trials comparing computer-assisted surgery with conventional surgery using the Stryker knee-navigation system and Duracon prosthesis. This trial is unique in that it is the first to use CT scans to assess all the coronal, axial and sagittal positions of the implanted components. In two equally matched groups of patients, it showed statistically significantly improved position on CT for femoral varus/valgus (p=0.032), femoral rotation (p=0.001), tibial varus/valgus (p=0.047), tibial rotation (p=0.011), tibial posterior slope (p=0.0001) and femoral tibial mismatch (p=0.037). There was further improved alignment on long leg standing Maquet limb alignment (p=0.004) and reduced blood loss (p=0.0001) in the computer-assisted group but longer OR times (p=0.0001) by a mean of 13 min. The trial showed clear improvement in component alignment in the computer-navigated group. The trial also produced one of the first measurements of total cumulative error when looking at component implantation. Here, the deviation from each of 7 CT-based component-alignment parameters was identified for each patient. Each deviation was then added together to give a cumulative error as displayed in Fig. 20.1.

The literature already suggests that malposition of the component by more than 3° in a single varus/valgus plane may lead to premature failure of the implant [16, 17]. When now looking at the reduction in cumulative error when using computer navigation, the results are significant and the distribution of conventional results
may explain accelerated polyethylene wear and failure seen in other series.

Sparman et al. [25] randomized 240 patients into a conventional and computer-assisted group, using the Stryker Knee navigation system and Scorpio prosthesis. This trial used long-leg weight-bearing films to assess coronal alignment, component position in the frontal plane and sagittal plane. The trial showed highly significant difference between the two groups in favor of navigation for all the parameters investigated. Only two out of 120 navigated knees had a post-operative deviation in the mechanical axis of 30, the conventional group 27 cases with 30 or more deviation (22%).

Krachow et al. [26] reported on 90 consecutive computer-assisted Duracon TKRs using the Stryker knee-navigation system and found that 79% of patients reviewed (81 out of 90) had long-leg films within one degree of neutral. The patients also had equal or better ranges of motion; knee and function scores at 1 year follow up. They concluded that the potential gains provided by such a system included faster rehabilitation, improved final range of motion, more complete extension and longer lasting knee replacements.

Clemens et al. [27] reported on a five-center, prospective randomized study between 1999 and 2001. 821 patients were enrolled into the study, 555 patients had navigated procedures and 266 had conventional procedures. The orthopilot navigation system and the SEARCH prosthesis were used in all cases. Implant accuracy was compared in four planes on plain radiographs together with long-leg-standing films to determine mechanical axis which gave 5 axes in total. Results were excellent in 49.6% for all five axes in the navigated group compared with 30.8% in the conventional group.

Stulberg [28] looked at the accuracy of conventional instrumentation using a navigation system. Whilst manual instrumentation allowed accurate frontal limb alignment, there was a tendency to hyperextend and internally rotate the femoral component and place excessive posterior slope on the tibia. Optimal alignment was achieved in only 4 out of 20 consecutive TKRs.

Bathis et al. [29] and Perlick et al. [30] reported a significantly more accurate mechanical axis using CT-based and image-free systems when compared to controls. They also applied navigation to ligament balancing, based upon the work of Katz et al. [31]. A rectangular extension gap was developed with soft-tissue releases; the knee was then moved into flexed position, a spreader tool was then inserted into the space. The navigation system stored this position and recommended the optimal component orientation to achieve a balanced, rectangular flexion gap. Using this concept for femoral component
rotation, a balanced flexion and extension gap was achieved in all patients in the navigated group.

Ritschl et al. [32] used the Galileo Navigation and Robotic system to look at ligament balancing and flexion/extension gaps. They found better gap balancing and improved stability in extension and flexion when using a computer-navigation system.

**Discussion**

Computer-navigation systems, despite their infancy, are clearly here to stay. Whilst the inaccuracies of conventional knee-arthroplasty surgery have been and continue to be documented, navigation systems have now presented the orthopedic surgeon with unrivaled accuracy in producing bone cuts. More importantly, for the first time the surgeon has an advanced biofeedback tool that can be used to his advantage when producing a balanced knee with a combination of accurate bone cuts and soft-tissue releases.

Already there are a number of articles published that show a clear improvement in alignment over the conventional gold-standard techniques. It logically follows that a better aligned and balanced knee should function better and for longer with less likelihood of revision than a poorly implanted component. However, as yet there are no kinematic studies or long-term outcome studies to show this – although the latter is presently a time-dependent phenomenon.

Navigation systems are changing both in terms of hardware and software. No longer are machines the size of large image intensifiers. Many manufacturers have broken machines into smaller components that can be free-standing, incorporated partially into existing OR facilities or integrated completely into an endosuite theater. Software updates arrive once or twice yearly as continuing improvements in our clinical knowledge of knee arthroplasty enables us to fine-tune or even radically change our thought process in performing a TKR. Indeed navigation and the information it has already given us, has led us to challenge a number of long-held beliefs regarding soft-tissue balancing and the ability to accurately determine a resection at a specified angle.

Instrument design is already changing as many manufacturers move to entirely extra-medullary systems. The ability to make universal cutting instruments will make instrument inventories smaller and easier for the OR staff. Many instruments such as IM rods may become obsolete as surgeons minimize the risk of fat embolus. Navigation has not just challenged the accuracy of traditional instrumentation but also challenged the process by which the cutting blocks and cuts have been made [33]. Altered configuration of pin holes in cutting blocks to increase stability of the blocks at the bone interface is a minor example whilst the inadequacies of current saw-blade technology is a more important variable that has been truly highlighted through the use of surgical navigation systems.

The accuracy that computer navigation affords, has led the surgeon to explore other aspects of total knee arthroplasty surgery. One of these is minimally invasive surgery where the accuracy of navigation will have a huge impact and is described in a separate chapter.

Computer-navigation systems will continue to evolve at a rapid pace, much as the general field of computing has done so over the past 20 years and it is not difficult to see how once financial cost issues are resolved, its use will be routine throughout the world within a few years.

**References**

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