Computer assisted navigation in orthopaedics and trauma surgery

Rohit Rambani

Mathew Varghese

Abstract

Computer assisted navigation was initially introduced into neurosurgical practice, and then orthopaedic spinal surgery, in the 1990's. It has gained momentum in recent years, finding applications in multiple branches of orthopaedic surgery including hip and knee arthroplasty, sports injuries, trauma, spinal surgery and bone tumour surgery. The technology provides the surgeon with real-time information regarding the position of surgical instruments and implants in relation to the skeleton and has the potential to improve surgical accuracy and outcome.

Computer assisted navigation systems can be active, employing robotic surgeons, or passive where the surgeon remains in total control but computer software aids in the procedure.

Computer assisted navigation has the potential to help surgeons perform procedures more accurately, with a view to improving outcome. This article reviews the multiple applications, limitations, and advantages of computer assisted navigation in orthopaedics in the operating theatre and beyond.

Keywords computer; navigation; orthopaedic applications

Introduction

Computer assisted navigation was first utilized in neurosurgical practice, aiding preoperative planning using CT, with the aim of increasing intraoperative accuracy. Initial applications were limited to needle biopsies and tumour resection, but provided insight into the potential for wider application of the technologies.[1–4]

The goal of computer assisted navigation was to improve understanding of the surgical field and thereby improve surgical accuracy and it entered orthopaedic clinical practice in the 1990's, helping to improve the accuracy of pedicle screw insertion[5] in spinal surgery.

Over the years that followed improvements in imaging techniques and computing technologies have made computer assisted navigation more user-friendly, leading to the development of applications in mainstream orthopaedics. It was, however, the use of the navigation in hip and knee arthroplasty that made industry and clinicians really take note. With wider acceptance, computer assisted navigation can be a useful tool in a variety of orthopaedic procedures such as hip and knee arthroplasty, sports injuries, trauma, and spinal and bone tumour surgery.[6,7]

***Rohit Rambani** MBBS MS Ortho FRCS (Tr & Orth) Senior Knee Fellow, Leeds Teaching Hospital NHS Trust, Leeds, UK. Conflicts of interest: none.*

***Mathew Varghese** FRCS (Tr & Orth) Specialist Registrar, Leeds Teaching Hospital NHS Trust, Leeds, UK. Conflicts of interest: none.*

Computer assisted navigation — the basics

Computer assisted navigation involves the integration of computer technology for preoperative planning and guidance or performing surgical procedures. Computer assisted navigation systems can be active, with the use of robotic surgeons, or passive where the surgeon is in total control but computer software aids in the positioning of instruments and implants relative to the patient's anatomy. The concept is often compared to that of the global positioning system (GPS) in cars.

A procedure-specific digital map is created with which surgical instruments can interact in real time, to mm accuracy. There are currently three methods of obtaining sufficiently accurate imaging to allow the positioning of instruments to be tracked intraoperatively, which classifies computer assisted navigation systems into CT based, fluoroscopy based and imageless.

- CT based imaging (more common in neurosurgical and spinal surgery) — CT scans of the operative site are obtained preoperatively and used to create 3 dimensional (3-D) images. The data is matched with the patient's anatomy after tracking markers, visible to the computer, are fixed to the patient. A pointing device, also visible to the computer, is then used to identify predetermined landmarks
- Intraoperative fluoroscopy based imaging (more common in trauma surgery) — Modified fluoroscopy with the help of computer software helps to create an anatomical map. Multiple fluoroscopic images can be acquired and processed by computer software to provide real time multiplanar images without the need for extensive fluoroscopy exposure. The software superimposes the position of surgical instruments and the path of an implant onto real time imaging, allowing the surgeon to modify implant trajectory without the need for further fluoroscopy. 3-D fluoroscopy is an evolution of this technique and consists of a mobile C-arm unit, modified to incorporate a motorized rotational movement that is linked to a computer to provide multiplanar 3-D images of bony structures.
- Image free — Computer software has an anatomical model, built up from a database of stored CT scans, for the procedure to be performed. The computer model is then augmented by 'surface registration' whereby a pointing device held by the surgeon, and visible to the computer, marks out predetermined areas of the patient's anatomy. This system avoids radiation exposure to the patient and surgical team.

Registration is the process by which the computer identifies bones and joints and logs their positions in space. All of the above techniques require registration before surgery can begin. This is an extremely important step, which is done by the careful and accurate placement of tracking markers identifiable by the computer system onto predetermined anatomical landmarks (Figure 1).

While computer assisted navigation has the potential to help surgeons perform procedures more accurately, individuals need a clear understanding of the goals, applications, and limitations

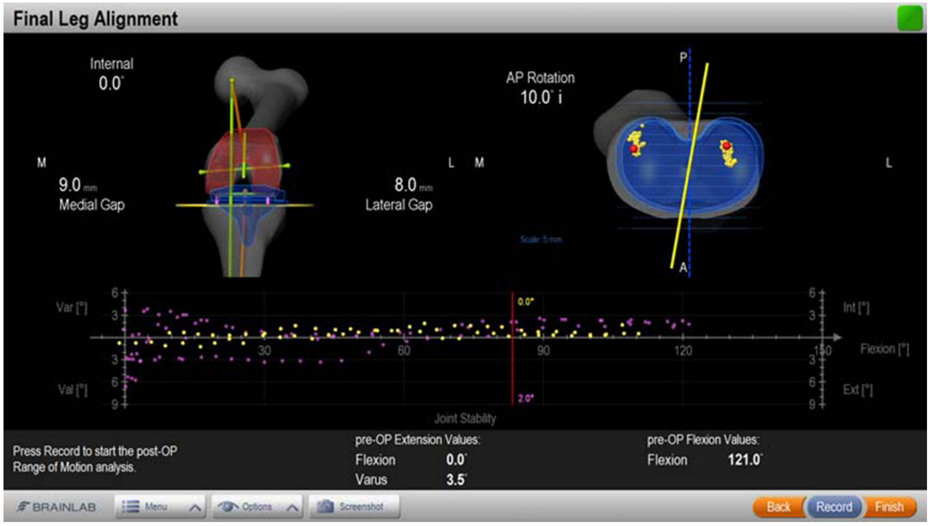

Figure 1 Screen print of the soft tissue balancing in total knee arthroplasty using navigation.

of these systems before embracing them into their clinical practice.

Navigation in total knee arthroplasty

The first evidence from navigation assisted total knee arthroplasty (TKA) was published in 1997.[8] There is a well-recognized relationship between accuracy and outcome in knee arthroplasty, and the potential for technology to improve implant positioning and mechanical alignment was a key-driving factor for computer assisted navigation in TKA. Component alignment in TKAs, within 3° of the mechanical axis, is crucial in order to achieve the best long-term implant survival. Studies have shown that conventional intramedullary or extra-medullary jigs fail to restore the alignment within 3° in 10%−38% of TKAs, even when performed by experienced surgeons.[9,10]

Navigation has been shown to improve the precision of surgical technique and implant alignment.[11−13] Other advantages include accurate restoration of the mechanical axis, dynamic and accurate assessment of the deformity, improved gap balancing and a decreased incidence of fat embolism due to the avoidance of intramedullary instrumentation (Figure 2).

Disadvantages, which currently also apply to most applications of computer assisted navigation, include the learning curve associated with embracing a new technology, prolonged surgical time, set up and maintenance costs and the lack of long-term evidence on clinical outcome.[14]

Revision TKA can involve dealing with significant bone loss, making referencing for implant position and alignment challenging with conventional techniques. Computer assisted navigation can be particularly helpful in such cases, as the system allows the mechanical axis to be checked at all stages and helps to fine-tune the orientation of the revision prosthesis in the sagittal and coronal planes.[14]

The literature remains clouded, however, regarding the benefits of computer-assisted navigation which are not yet proved. The meta-analysis by Bauwens et al.[15] compared navigated TKA with conventional TKA and showed no difference in alignment to the mechanical axis between the two groups, although malalignment >2−3° was less likely in the navigated TKA group. Other findings of note included an increased operating time of 23%. Many other studies report on the benefits of computer assisted navigation in terms of mechanical alignment but how this translates into improved clinical outcome has yet to be shown.[16,17]

The absence of long-term evidence on outcome and survivorship, and the increased costs associated with navigated TKA, are likely to limit the uptake of the technology for now. Multicenter randomized controlled trials with long-term follow up comparing navigated TKA with conventional TKA are needed to show the true clinical benefit.[18]

Navigation in total hip arthroplasty

Computer assisted navigation systems in total hip arthroplasty (THA) are available as active (robotic) and passive (surgeon navigated) forms, the latter being more commonly used.

The correct positioning of the implants in THA is vital for optimum long-term survivorship and functional outcome, and is guided by preoperative imaging and templating, intraoperative assessment of the patients anatomy and mechanical alignment jigs. Mechanical alignment jigs are known to have limitations in terms of accurate implant placement.[19] The patient's position on the operating table is also a key factor in determining correct implant placement but can be variable. Poor positioning of the acetabular component has been shown to result in higher rates of asymmetric polyethylene wear, pelvic osteolysis and implant migration.[20]

The majority of surgeons aim to position the acetabular component in the "safe zone" described by Lewinnek et al.[21] for optimal outcome. The correct restoration of leg length is also essential to avoid potential pain, stiffness and early implant failure.[22]

Navigation assisted THA has gained in popularity recently, as surgeons seek to improve the positioning of implants. The recent meta-analysis by Gandhi et al. concluded that navigation in hip arthroplasty improves the precision of acetabular cup placement over freehand alignment by decreasing the number of outliers

