Chapter 13: Spinal Navigation
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I. Key Points
- Allows intraoperative real time navigation of instruments relative to the spinal anatomy
- Provides 3-D real time anatomical information
- Increases the safety, accuracy and efficiency of certain spine procedures
- Eliminates the intraoperative radiation exposure to surgeons and operative staff members during cases
- Provides a versatile array of usage facilitating the ability to perform complex spine surgery safely

II. Description

Introduction
Spinal Navigation uses computer vision technology to plan and guide surgical interventions. It has evolved from a cumbersome to more user friendly system. Early generation systems required a complex pre-registration process through either paired-point technique or surface mapping. These techniques introduced the potential for error and were time consuming but critical in linking image data to spinal anatomy. Most resistance to universal adoption of image navigation stemmed from such factors. Newer systems now combine high precision robotics with unparalleled imaging capability eliminating the difficulty and need for pre-registration. Computer aided surgery now enables acquisition of imaging data intraoperatively prior to incision. Current software can use either a 2-D or 3-D image data set acquired intraoperatively by a fluoroscopy unit or high resolution computer tomography (CT) scanner. These images are then automatically imported into the computer workstation and used to create a 3-D picture of the patient’s anatomy completing the registration process. This automatic registration
process improves the anatomical localization accuracy and eliminates the need for manual point based or surface based registration. Subsequently real time tracking data is matched with previously obtained image data through the use of a fixed reference point on the patient, computer workstation and camera system. For spine procedures affixing the fixed reference frame/point to bone is the initial step in registration. (Fig 1,2)

**Components of a Navigation System**

After the intraoperative image data is obtained through one of the commercial systems available this data set will be automatically uploaded to the computer workstation. A 3-D image is created and will be linked to your working position relative to the patient’s anatomy through a tracking system. There are currently 2 types of tracking systems which will triangulate your position in space; optical or electromagnetic-based. Both systems will allow localization of your surgical instruments or implants in real time. In electromagnetic (EM) tracking an EM field is created and changes in field are monitored to localize a tracked device. With optical tracking, cameras track the position of instruments relative to the fixed reference point through an active or passive method. Active tracking entails LEDs on the instruments emitting light and passively involves the reflection of infrared light from the camera to the reflective spheres on instruments. Both systems require a direct line of view between the camera and the tracked instruments to link surgical anatomy to the 3-D data set in the computer workstation. The system can then triangulate the instruments tip location, angle and trajectory. Both systems are comparable in positioning accuracy and can provide real time, precise, 3-D imaging quality. (Fig 3)
Applications/Advantages

Image navigation technology has led to many innovative, versatile uses in spine surgery. It has improved the safety and ability to perform complex procedures where visibility is not optimal or anatomical deformity is present. Numerous published studies are demonstrating its effectiveness in improved pedicle screw placement in complex multiplanar spinal deformities.\(^1\)-\(^4\). A meta-analysis of pedicle screw placement accuracy has also demonstrated a 95% median accuracy with navigation compared to 90% without it.\(^5\). The capability to visualize a pedicle in 3-D, intuitively should minimize screw insertion risks associated with pedicle asymmetry, smaller diameters and vertebral rotation thus avoiding nerve root or spinal cord compression. With improved accuracy operative times have also been shown to decrease with the use of image navigation.\(^6\).

Speculative limitations regarding increased operative time, patient registration and data acquisition have not been justified with the current real time intraoperative data acquisition technology/software systems.\(^2\),\(^6\). In addition mean radiation exposure using image navigation has been shown to be statistically significantly less compared to conventional fluoroscopy.\(^7\). UlHaque\(^8\) et al has also demonstrated that fluoroscopically assisted pedicle screw insertion for adolescent scoliosis will have exposed a spine surgeon to radiation levels exceeding established lifetime dose limits over his career.

Aside from pedicle screw insertion many versatile applications are now being described for image navigation including: C1-2 transarticular and percutaneous translaminar facet screw placement, lumbar disk arthroplasty placement and balloon kyphoplasty. These possibilities are incorporating the advantages of image navigation and demonstrating feasibility, accuracy, and operative time reduction while reducing radiation exposure.
Clinical Value

Spinal Navigation is an exciting technology which is continuously adding to the ability, efficiency and accuracy in treating a variety of complex spine problems. The primary reason for its implementation is to improve overall patient care by decreasing surgical risks. The enhanced wide, real time, 3-D visualization, decreased radiation exposure and increased safety has made this technology very practical. It can allow for a more minimally invasive exposure and reduce operative times. These beneficial effects have been well documented in the literature and slowly image navigation surgery is becoming a more widely accepted and practiced addition to spine surgery.

Despite a high acquisition cost, the return on investment when considering the reduction of revision surgeries for misplaced symptomatic hardware, improved surgical outcomes, faster patient recovery from less surgical trauma and fewer complications may long term outweigh its expense. Further studies and ongoing advances in spinal navigation technology will continue to challenge cost limitations and refine our understanding of outcome efficacy in patient care.

III. Surgical Pearls

1-All staff using the system should be properly trained to avoid any errors that can lead to improper set up, inaccurate information and surgical complications

2-The fixed referenced frame should not be inadvertently bumped, moved or altered. This can lead to tracking and positional errors while navigating. It’s important to keep reference frame close to the surgical field for maximum accuracy
3-Spinal Navigation does not substitute for fundamental knowledge of anatomical landmarks and appropriate surgical technique. Improper use of system or malfunction can cause navigational inaccuracies.

4-Image Navigation should be used to confirm anatomical landmarks and suspected locations and trajectories for hardware placement

5-Preoperative plan room set up including: camera, computer workstation and reference frame position to ascertain a direct line of view between navigation components.

IV. References

2. Rajasekaran S., Vidyadhara S., Ramesh P., Shetty A. Randomized Clinical Study to Compare the Accuracy of Navigated and Non-Navigated Thoracic Pedicle Screws in Deformity Correction Surgeries. Spine. 2007;32,2:E56-E64
V. Key Illustrations

Figure 1 - Reference Frame percutaneously fixed to the posterior superior iliac spine (PSIS) of the pelvis allowing registration prior to incision

Figure 2 - Reference Frame could also be attached via a spinous process clamp after exposure. Often used for posterior cervical or thoracic exposures/instrumentation

Figure 3 - Examples of 3-D images with navigation provided by the computer workstation with a superimposed projection of navigated instrument or probe

VI. Questions

1 - Spinal image navigation will provide all of the following except

A-real time views
B-decreased operative times
C-axial views
D-increased radiation exposure
E-improved accuracy

2- Spinal image navigation has affected all of the following except

A-pedicle screw placement
B-revision exposures
C- hardware removal
D-decreased surgical risks
E- radiation exposure

3-Current spinal image navigation systems provide real time tracking through

A-paired point pre-registration technique
B-surface mapping pre-registration technique
C-continuous fluoroscopic imaging technique
D-optical or electromagnetic based techniques
E-none of the above