Chapter 9

ADVANTAGES OF COMPUTER ASSISTED PEDICLCE SCREW PLACEMENT

Transpedicular screws are commonly used for intervertebral fixation in various spinal disorders. Transpedicular screw insertion is a demanding technique due to considerable variability in the human anatomy and to the fact that it is impossible to guide a screw exactly in three planes of space based on the two dimensional image information of fluoroscopy. Before the advent of image guidance, intraoperative spinal navigation was based on the surgeon's knowledge, experience, and judgment combined with information gathered from serial radiography or fluoroscopy. Monitoring of nerve and/or spinal cord status can provide data regarding the function of these structures (and, indirectly, whether or not a spinal instrument or implant may be placing this function at risk) but is only an indirect indicator of instrument position. Plain radiography is still commonly used by many surgeons to assist in localizing the skin incision and/or the proper anatomic level for procedures such as microdiscectomy. One of the drawbacks of plain radiography is that a significant amount of time can elapse while the films are being obtained and processed. This time factor is multiplied when unsuitable images are obtained.
because they process must be repeated. The other disadvantage of radiography is that only static images can be acquired; thus, information regarding instrument position within the surgical field cannot be immediately updated. C-arm fluoroscopy addresses many of these concerns, leading some surgeons to use fluoroscopy as their primary means of intraoperative spinal navigation.

Fluoroscopy can be used to acquire multiple images in succession, or it can be used continuously to obtain immediate updates of an instrument's position. A variety of spinal instrumentation procedures can be performed using fluoroscopy. One of its main disadvantages is the potential for significant occupational radiation exposure, particularly when continuous fluoroscopy is used. Further more, when using a single fluoroscope, images can be obtained in only one plane at a time. If another plane of view is desired, the C-arm must be repositioned. Two separate fluoroscopes are needed for intraoperative navigation during procedures that require simultaneous biplanar fluoroscopy, such as odontoid screw placement. Lastly, a C-arm itself is quite unwieldy and can create ergonomic constraints that hinder access to the surgical field. Factors such as poor imaging, complex anatomy, and anatomic variability can make intraoperative spinal navigation even more difficult. Consequently, conventional methods of intraoperative
spinal navigation have some significant limitations. For instance, several laboratory and clinical studies have shown that lumbar pedicle screw insertion using standard techniques yields misplacement rates that range from 20% to 30%. In contrast, pedicle screw misplacement rates using image guidance range from 0% to 4%. Spinal image guidance was developed to address the shortcomings of conventional intraoperative navigation and to optimize the accuracy and safety of spinal instrumentation procedures.

Pedicle screw malplacement rates of between 15 and 50% have been reported in clinical studies with conventional insertion techniques and an adequate postoperative CT assessment. Castro et al. reported that 49 out of 123 pedicle screws (39.8%) perforated the pedicle wall. They had five nerve root complications. Gertzbein and Robbins found 48 out of 167 screws (28.7%) penetrating the pedicular cortex. Two of them caused minor neurological complications.

Spinal image guidance was adapted from intracranial frameless stereotaxy, which used skin surface markers for registration (matching of the image anatomy to the surgical anatomy). These superficial markers were initially tried for spinal applications as well. Unfortunately, significant registration inaccuracy due to relative movement between the mobile skin
surface and the underlying bony anatomy occurred. Several clinical studies determined that spinal image guidance was not reliable because of this.\textsuperscript{9,10} Despite this initial difficulty, interest in spinal image guidance continued, and an effective method of registration soon emerged. Foley and Smith\textsuperscript{6,11} reported the use of anatomic landmarks on the dorsal aspect of the spine as fiducial (registration) markers in association with a dynamic reference array (DRA). These anatomic fiducials replaced the skin surface markers and provided reliable registration accuracy. The markers also augmented the flexibility of the system, as the registration points could be added or changed intraoperatively. The DRA attached directly to the spine and further optimized accuracy by alerting the computer workstation to any changes in spine position that occurred during the procedure. Kalfas et al\textsuperscript{12} and Nolte et al\textsuperscript{13} also performed some of the early investigational research using similar image-guided techniques to improve the safety of lumbar\textsuperscript{6} pedicle screw placement. Once the problems with registration inaccuracy were solved, the popularity of spinal image guidance began to increase. As technology improved, second generation CT and fluoroscopy-based systems were soon developed. Surgeons expanded the use of image guidance to more complex procedures throughout the entire spine, such as thoracic pedicle screw insertion\textsuperscript{14,15} and C1-C2 transarticular screw placement\textsuperscript{16,17}
This comparative study supports conclusions already published\textsuperscript{12,14,16} about the improved accuracy of pedicle screw insertion with computer assistance. A higher accuracy, with perforation rates of between 3.3 and 4.3\% has been achieved using computer-assisted techniques \textsuperscript{1, 11, 12, 14}. No randomised controlled clinical trials comparing conventional versus computer-assisted pedicle screw insertion are available to date. The purpose of the present study was to evaluate whether pedicle screws can be inserted more accurately and safely with computer assistance than with conventional methods in a randomised controlled series of 50 pedicle screw fixation in cadaver.

9.1 FUTURE IMAGE-GUIDED ADVANCEMENTS

2D-3D registration. The ideal spinal navigation system would combine the convenience of virtual fluoroscopy (C-arm based, no need for anatomic registration) with the anatomic visualization provided by CT-based systems. One means of doing this is to correlate intraoperatively acquired two-dimensional fluoroscopic images with preoperatively acquired three-dimensional CT images. This process, termed 2D-3D registration, exists. Several manufacturers provide software packages that perform this function. However, there are disadvantages to this approach. First of all, the process is
not automated (surgeon input is required). Second, there is still a need to obtain a properly formatted preoperative CT. Lastly, the accuracy of current 2D-3D registration techniques is questionable. Future development will likely include enhancements of the 2D-3D registration process.

9.2 THREE-DIMENSIONAL C-ARM FLUOROSCOPY

Three-dimensional C-arm fluoroscopy (3D fluoroscopy) is a significant advancement in the rapidly developing field of image guidance and potentially represents the future of intraoperative spinal navigation. Unlike a standard fluoroscope, an isocentric C-arm is able to automatically rotate around the patient while maintaining the relevant spinal anatomy in its center. With the addition of specialized software, such a C-arm can effectively function as a computed tomography scanner. The automated image acquisition takes approximately 2 minutes. The images are then reconstructed to provide axial, coronal, and sagittal views of the anatomy. The multiplanar constructions are of high quality and with regards to anatomic detail are comparable to images produced by an actual CT scanner. The isocentric C-arm can be used in conjunction with IGS technology to create a novel method of spinal image guidance. This requires
that the C-arm be fitted with a calibration target and that a DRA is attached to the patient. An electro-optical camera is then able to track the position of the DRA in reference to the C-arm while image acquisition takes place. The reconstructed images are transferred to the computer workstation and automatically uploaded into the IGS software in a process that takes 1 minute. Since the images are obtained with reference markers on both the C-arm (the target) and patient (the DRA), anatomic registration is not necessary for navigation. This process is somewhat analogous to virtual fluoroscopy, except that the images are identical to those provided by CT-based systems. As with current image-guided technology, virtually any surgical instrument can be tracked in reference to the reconstructed spinal anatomy. The advantages of this innovative technology are many. The isocentric C-arm provides three-dimensional reconstructed images of the patient on the operating table. Therefore, the risk of navigation inaccuracy due to intervertebral alignment differences between the preoperative CT data set and the intraoperative position is eliminated. Since the system can display three adjacent lumbar vertebrae, separate registration solutions are unnecessary. The need for a preoperative CT scan with a specific image-guided protocol (and its cost in money and time) is eliminated. The surgeon-driven registration process is
completely obviated, as navigation can commence immediately after the images have been transferred to the workstation. Since spinal exposure is unnecessary, this provides an ideal opportunity for the integration of IGS with minimally invasive techniques such as percutaneous pedicle screw placement, minimally invasive decompression, and thoracoscopy. The isocentric C-arm can serve as a standard C-arm fluoroscope, maximizing its use by the OR when image-guided cases are not being performed (no "down time") and allowing a single device to serve as both C-arm and CT during image-guided cases. Lastly, a postoperative scan can be performed in the operating room to ensure accurate implant placement and/or to evaluate the thoroughness of a decompressive procedure: )-

This original research work did not have any commercial affiliations to the manufacturers of navigation systems.
REFERENCES


8. Gertzbein SD and Robbins SE. Spine 1: (1990) 11


