Image-guided surgery: applications to the cervical and thoracic spine and a review of the first 120 procedures

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Object. The authors undertook a study to demonstrate that frameless stereotaxy can be applied safely to the cervical and thoracic spine to minimize complications and associated morbidity.

Methods. A retrospective review of cases was conducted involving the use of an image-guidance system for the accurate placement of surgical implants or for resection of lesions within the cervical and thoracic spine. The outcome measures considered were neural injury, vascular injury, wound infection, surgical revision, and death.

Conclusions. Image-guidance systems are useful intraoperative tools that can be applied accurately to spinal surgery. In addition, such systems can be of great use in the preoperative planning of complex spinal surgery.

KEY WORDS • image guidance • cervical spine • thoracic spine • frameless stereotaxy

Image-guided surgery in which frameless stereotactic techniques are used was introduced in 1992 and has become an established technique in intracranial surgery, with the images being reconstructed from CT or magnetic resonance imaging. However, the application of similar techniques to the spine has been limited largely to transoral odontoid procedures. The major problem encountered in attempting to apply image-guidance systems to the spine is that of maintaining accurate registration coordinates because of problems involving the relative articulation between vertebral bodies. The development of infrared detection and dynamic tracking of vertebral bodies has allowed image-guidance techniques to be applied to the articulated spine. Recently, reports have emerged in which the authors focus on the application of this new technology to a variety of spinal procedures, particularly the insertion of lumbar pedicle screws, the potential for accurate placement of transarticular screws, and anterior cervical procedures. Much of the work for image guidance in the spine is based on in vitro studies, and very little information has actually come from clinical studies.

Clinical Material and Methods

We have used a frameless stereotactic image-guidance system (StealthStation; Sofamor Danek, Memphis, TN) for complex spinal surgery in 120 patients.

In all patients preoperative CT scans (1.5-mm axial slices) were obtained across the area of surgical interest. The raw data were transferred to the StealthStation via an ethernet connection. Three-dimensional reconstruction of the data was performed on the StealthStation, and points were sequentially registered in cases involving multiple affected vertebrae.
For anterior cervical procedures, image-guidance tracking was provided by a novel LED array attached to a modified Caspar retractor (Fig. 2) that provided dynamic referencing for the image-guidance system, allowing accurate surgery to be conducted at the level of the intervertebral disc. Registration of preoperative images was achieved by point matching of perioperatively selected points, identifiable both in the patient and on the preoperative images, combined with a surface-matching algorithm (Surgical Navigation Technology, CO).

For transarticular screw fixation in patients with atlantoaxial instability, the image-guidance system was used to guide screw placement through the lateral mass of C-2 (Fig. 3 upper and lower), avoiding the vertebral artery groove and spinal canal. Once this had been achieved, subsequent screw insertion into C-1 was performed by reverting to traditional guidance technique in which orthogonal fluoroscopic images were obtained from a C-arm. Thus, registration was to C-2 in isolation. The reference arc was attached to the spinous process of C-2, and multiple points and surface matching to C-2 allowed accurate guidance.

In thoracic procedures the reference arc was attached to the spinous process of the vertebra of interest, and the exposed posterior elements were registered.

Results

The procedures included atlantoaxial transarticular screw placement (34 cases), lateral mass plating (22 cases), thoracic pedicle screw insertion (16 cases), anterior cervical decompression (40 cases), and vertebrectomy (18 cases). In some patients more than one type of procedure was performed. A total of 368 screws were inserted. The diagnoses included rheumatoid arthritis in 44 patients, trauma in five, pseudarthrosis associated with ankylosing spondylitis in two, tuberculosis in one, degenerative cervical disease in 58, and neoplastic conditions in 10 patients.

Transarticular Screws Placed in C1–2

Image-guided C1–2 transarticular screw placement was attempted in 34 patients, in whom rheumatoid arthritis with C1–2 subluxation had been diagnosed in 32. Two patients had traumatic pedicle fractures of C-2 with instability of the C1–2 complex. Five patients had C-2 pedicle defects caused by an anomalous VA. In one case the defects were bilateral. In the four patients with a unilateral defect a unilateral C1–2 screw was inserted, and an adjunctive stabilization technique was performed using posterior C clamps. In the remaining patient bilateral defects prevented C1–2 screw insertion, and stabilization was achieved using a Ransford loop. In seven patients the image-guidance system was adapted to assist in the placement of 15 lateral mass screws and two transpedicular screws in addition to C1–2 fixation. In this series of 34 patients a total of 72 screws were inserted using image guidance. In one patient subsequent screw failure necessitated a fixation procedure in which a Ransford loop was used. One patient died of complications of fibrosing alveolitis unrelated to surgery at 70 days postoperatively. This was the patient in whom Ransford loop fixation was undertaken when pedicle size prevented the use of transarticular screws. There were three cases of postoperative superficial wound infections, all of which were managed without removal of implant. There were no cases of VA injury, spinal cord injury, and no injury of the C-2 nerve root.

Lateral Mass Plates

Twenty-two patients underwent placement of lateral mass plates as a primary procedure, including seven patients previously mentioned who underwent C1–2 transarticular screw fixation. A total of 153 lateral mass screws were inserted in 22 patients. Of these, three patients harbored extensive cervical tumors: an osteoblastoma in one patient (Fig. 4), a hemangioblastoma in the second, and a large destructive schwannoma in the third. In this series
there were no cases of cervical cord or nerve root injury. There was one case of VA injury not associated with screw insertion but related to dissection of the tumor from around the VA. Preoperative angiography had revealed that there was adequate blood flow in the contralateral VA. The ipsilateral VA was therefore sacrificed. The patient suffered no ill effects. There were two postoperative wound infections. Neither of these required reoperation or removal of the metal implants. There were two cases of screw pullouts, of which one was total, but in neither case did this compromise the integrity of the implant, and thus there was no incidence of implant failure or reoperation.

**Thoracic Pedicle Screws**

Thoracic pedicle screws were inserted as a primary procedure in 13 patients, in five of whom an anterior stabilization had previously been performed using a Kaneda system (Fig. 5). In these five patients image guidance allowed the insertion of posterior pedicle screws into the same vertebra as the Kaneda device by selecting a trajectory so as to avoid the anterior screws from the Kaneda device. Thus, a rigid parallelogram of fixation across the area of interest was achieved. In three other patients thoracic pedicle screws were also inserted in addition to lateral mass plating of the cervical spine. Levels into which pedicle screws were inserted included the entire thoracic spine from T-1 to T-12. Of these 16 patients, three had been diagnosed as having rheumatoid arthritis, three as having a traumatic subluxation of the thoracic spine, one as having tuberculosis of the thoracic spine, two as having pseudarthrosis complicating ankylosing spondylitis, six as having metastatic tumors to the thoracic spine, and one patient as having a thoracic schwannoma.

There were three postoperative wound infections. One serious complication resulted in the patient’s death 3 weeks following surgery from disseminated methicillin-resistant *Staphylococcus aureus* sepsis. This occurred in a patient with rheumatoid arthritis with poor respiratory reserve in whom a transthoracic decompressive and stabilization procedure was contraindicated and a posterior decompression with pedicle screw fixation had been attempted instead. There was no incidence of spinal cord or nerve root trauma, and there was no case of implant failure.

**Anterior Cervical Surgery**

Image-guided anterior cervical surgery was performed in 58 patients for degenerative spondylosis of the cervical spine. In 40 patients anterior cervical decompressive surgery alone was performed. In the remaining 18 patients a vertebrectomy was performed in which iliac crest graft was secured anteriorly by using an anterior plate and screws. A novel registration technique combined with the use of an LED array and modified Caspar retractor permitted acute registration. Image guidance was used to identify lateral resection margins for osteophytes in 24 patients (Fig. 6), for resection margins in relation to the transverse foramen in nine patients, and for the insertion of 72 anterior cervical screws for fixation of the anterior plates. Screw position was evaluated intraoperatively by using the C-arm image intensifier, having previously determined optimum screw trajectory with the StealthStation.

See Table 1 for a summary of procedures performed and number of screws inserted and Table 2 for a summary of pathological conditions encountered and the procedures used to treat the conditions.
Discussion

Much has been written regarding the use of image-guidance systems for intracranial procedures. The use of computers to assist surgeons has benefits that range from preoperative planning and helping to define complex or disrupted anatomy to intraoperative guidance to maximize safety while allowing for adequate resection and placement of instrumentation to obtain an optimum surgical result. Without image-guidance systems, the risk of neurological damage to the spinal cord or nerve roots is quoted as 0.2 to 1%, and vascular injury that may occur in up to 5% of cervical spinal procedures can have devastating consequences. In addition patients who do not progress well after cervical spine surgery have in many instances undergone inadequate decompression of the neural structures that necessitates a reoperation.

Recently spine surgeons have started to focus their efforts on the challenge of applying image-guidance technology to complex spinal procedures. Initially it was believed that there would be few clinical uses for such systems in spinal surgery because of the problem of excessive inaccuracy when using skin surface markers for registration purposes. However, early on it was demonstrated that the technique could be used to assist in the accurate placement of pedicle screws. Developments in the technique of securing a reference arm to the targeted vertebrae have, to a large extent, overcome the initial problems of inaccuracy. It has been shown in vitro that interactive image-guided stereotaxis can offer an increased margin of safety for placement of transarticular screws through the atlantoaxial complex and for lumbar pedicle screws.

The accuracy of registration has to be addressed again when considering application of image guidance to the anterior cervical spine. A limited number of studies have been recently published relating to anterior cervical surgery. In our own preliminary experience we addressed the problems associated with obtaining accurate reliable registration of the image-guidance system and outlined an acceptable solution when performing surgery on anterior spinal structures. In essence, a preoperative CT scan of the relevant vertebrae must be obtained in a similar position to

<table>
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<tr>
<th>Primary Procedure</th>
<th>No. of Primary Procedures</th>
<th>No. of Screws Inserted</th>
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<tr>
<td>anterior cervical discectomy</td>
<td>40</td>
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<tr>
<td>cervical vertebrectomy</td>
<td>18</td>
<td>72</td>
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<tr>
<td>pedicle screws</td>
<td>13</td>
<td>90†</td>
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<td>C1–2 transarticular screws</td>
<td>34</td>
<td>53</td>
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<tr>
<td>lat mass screws</td>
<td>15</td>
<td>153</td>
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<tr>
<td>total</td>
<td>120</td>
<td>368</td>
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* Regardless of primary procedure.
† Includes two cervical pedicle screws.
that adopted during surgery, and a combination of point matching and surface mapping, by using geometrical landmarks, which is then subjected to statistical matching, minimizes any error.1

We admit that there can be a considerable learning curve involved in applying intracranial techniques to the spine; however, we believe that the benefits offered by image-guidance systems outweigh the disadvantages, especially when applied to complex spinal cases.

It is our belief that image-guided surgery performed in the cervical and thoracic spine has several advantageous applications. The system is useful for preoperative evaluation and surgical planning. For example, in our five cases of C1–2 fixation in which there was a defective pedicle, it was known preoperatively that only a unilateral screw could be accommodated in four cases and that an alternative procedure was required for the fifth patient. Additionally, in the cases of the five patients with Kaneda screw systems in whom thoracic pedicle screws were also inserted, image guidance was invaluable. Image guidance aids in the identification of important anatomical structures such as the VAs, the borders of the spinal canal, and nerve root foramina. In particular it is beneficial because it accurately identifies abnormal anatomy such as tumors, lateral mass defects, and bone destruction that may occur in cases of rheumatoid arthritis or infection.17,18

In addition we have found it possible to determine the best screw trajectory in an individual patient rather than having to rely on a population-based, predetermined global trajectory. Thus, not only can hazardous structures be avoided but a trajectory can also be selected that places the screw in the best quality bone or with the longest bone purchase for an individual patient.

The use of image-guidance systems has been criticized for prolonging anesthesia time and also for introducing an additional imaging component in some instances. In our opinion CT scanning performed through the C-2 pedicles is a sensible and necessary investigation when considering the placement of instrumentation in this area. Delays are inevitably encountered when familiarizing oneself with new technology. However, in our current practice all preoperative planning is performed while the patient is in the anesthesia room and the perioperative registration does not significantly add to the operative time. Indeed, in complex cases we believe the operative time may be reduced because of the additional confidence and benefits that the system confers.

Conclusions

There are numerous factors responsible for surgery-related complications in procedures of the spine. These include the use of instrumentation within the spinal canal, extensive lateral dissection, operating when the direct line of vision is restricted, and operating in regions of variable, inconsistent anatomy. Computer-aided image-guidance systems provide a three-dimensional solution to a three-dimensional problem. Future developments include the application of frameless image-guidance techniques to percutaneous and multiple-level registrations, which will further enhance the perioperative versatility of this technology.

Disclosure

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References


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