The placement of lumbar pedicle screws using computerised stereotactic guidance

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Computer-assisted frameless stereotactic image guidance allows precise preoperative planning and intraoperative localisation of the image. It has been developed and tested in the laboratory.

We evaluated the efficacy, clinical results and complications of placement of a pedicle screw in the lumbar spine using this technique. A total of 62 patients (28 men, 34 women) had lumbar decompression and spinal fusion with segmental pedicle screws. Postoperative CT scans were taken of 35 patients to investigate the placement of 330 screws. None showed penetration of the medial or inferior wall of a pedicle. Registration was carried out 66 times. The number of fiducial points used on each registration averaged 5.8 (4 to 7). The mean registration error was 0.75 mm (0.32 to 1.72).

This technique provides a safe and reliable guide for placement of transpedicular screws in the lumbar spine.

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The pedicles are the strongest part of the vertebra. Segmental pedicle screw fixation provides multidimensional control of the instrumented section and gives greater rigidity with an improved fusion rate compared with traditional forms of fixation. The pedicles are intimately related to the neural elements which are particularly susceptible to injury by violation of the medial or inferior cortex. The technique of insertion is usually ‘blind’ since the pedicle is not directly visible. Roy-Camille, Saillant and Mazel reported that 10% of the transpedicular screws in their early series (1988) were incorrectly placed. Radiological localisation of the pedicles and evoked electromyographs (EMGs) have been used to confirm correct placement of pedicle screws, but Weinstein et al reported an overall rate of misplacement of 21%, with frequent false-positive and false-negative results in the radiological assessment of the location of the screw. In 1996 Castro et al using CT showed that the screws were incorrectly placed in 25% of cadavers and in 40% of pedicles of patients. Stimulus-evoked EMG monitoring is a sensitive and reliable technique for detecting perforations of the pedicle, but ‘after-the-fact’ monitoring will not prevent an acute nerve injury.

Image-guided surgery using preoperative CT or MRI for localisation and navigation has been successfully applied in intracranial surgery, systems have been introduced recently for guidance during insertion of pedicle screws which have shown good results in laboratory tests and after clinical surgery. The Stealth Station (Surgical Navigation Technologies Inc, Colorado) computer and monitor containing an image-guidance algorithm using a three-dimensional (3D) digitiser and infrared light-emitting diodes (LEDs) attached to the surgical instruments, allows the clinician to locate a point in image space and match it to the surgical space. This is an instantaneous process as opposed to the five-minute delay which is associated with previous stereotactic techniques. Accuracy of localisation has been demonstrated in the laboratory and in cranial surgery. Our aim in this clinical study was to determine the safety and effectiveness of the Stealth Station in the placement of pedicle screws.

Patients and Methods

We studied 62 consecutive adult patients (28 men, 34 women) with a mean age of 53 years (19 to 83) undergoing decompression of the lumbar spine and posterior fusion with pedicle screws. The indications for surgery were spinal stenosis and lumbar instability in all cases. Six patients (10%) also had scoliosis and two had pseudarthrosis after previously attempted fusion. The exclusion criteria were poor CT data because of motion artifact during scanning, instrumentation in the cervical or thoracic spine, and instrumented fusion without decompression. In all patients the somatosensory evoked potentials (SSEPs)
and stimulus-evoked EMG were monitored during the operation. The duration of surgery was recorded for several standard steps of the procedure including the use of the image guidance. Postoperative CT scans were obtained in the first 35 patients enrolled in the study.

During the preoperative visit, an axial CT scan of the surgical site was obtained to ensure that the image slices were 1.0 to 2.0 mm in thickness, were constant and contiguous, did not overlap, were obtained without gantry tilt, had no bone windows, and contained the smallest field of view which encompassed the region of interest. The imaging information was downloaded to the Stealth Station. This was achieved using an optical data disc although a tape or a local area network may be used.

The patients were prepared for surgery in standard fashion. The CT data were verified for correct orientation and a 3D reconstruction created together with axial, coronal, and sagittal biplanar images. 3D and biplanar images can be manipulated at will using a standard mouse-pointer system. The Stealth software application is based on a Windows platform (Microsoft Inc, Redmond, Washington). Anatomical landmarks (fiducial points) which can easily be identified during surgery were selected on the posterior reconstructed CT image using the mouse-pointer. Widely disparate points, such as the tips of the transverse processes and spinous processes at contiguous levels, were preferred (Fig. 1). At least three points were selected at each segmental level. These fiducial points were recorded and saved.

A camera connected to the Stealth Station, positioned 1.83 m from the ground at the patient’s feet, provided an unobstructed view of the surgical site. After a standard operative exposure, a spinal reference marker containing LEDs was attached to a fixed skeletal point such as a spinous process (Fig. 1). A point probe, also containing LEDs, was placed in contact with the spinal reference marker to confirm that the camera could locate these two instruments in relation to each other. The probe was then used to touch each of the anatomical landmarks corresponding to the preselected fiducial points marked on the posterior image of the CT reconstruction (Fig. 2). Since the camera identifies the spatial position of the probe and the spinal reference marker, each of these anatomical points was sequentially registered in relation to this marker. A three-dimensional ‘map’ of the relevant spinal segments was then created. The correlation between the registered map and the CT reconstruction had to be within 2 mm to proceed with insertion of the image-guided screw (Fig. 3). Once achieved, the tip of the point probe was placed on any anatomical structure in the vicinity of the spinal reference marker and its location viewed on axial, coronal, or sagittal biplanar CT images on the computer monitor. A trajectory in continuance with the shaft of the probe could be viewed on all of the biplanar images. This allowed the surgeon to identify the optimal entry point for the pedicle and its exact disposition to allow optimal fit of the screw.

Intraoperative fluoroscopy or radiography was not used. When an acceptable entry point and the alignment were verified, an awl was used to mark the entry point; a LED containing a drill guide confirmed alignment and the pedicle pathway was drilled to the proper depth. The depth of drilling and the width and length of the screw were determined from reformatted images (Fig. 4). The point probe was used to assess the direction of the hole followed by a

Fig. 2
The Sharp probe and arch with LEDs.

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ball-tipped pedicle feeler to confirm the integrity of the pedicle walls. The hole was tapped and the screw inserted. Only after all the screws were in position was decompression carried out. After decompression a visual and tactile inspection of each pedicle assessed the integrity of its walls. The complications from the surgery and from the procedure were recorded. CT scans, obtained on the initial 35 patients, were analysed by an independent radiologist and two reviewers.

**Results**

A total of 330 pedicle screws was inserted. Registration was carried out 66 times. The mean number of attempts which achieved a registration accuracy of within 2 mm was 1.75 (1 to 7). The mean number of fiducial points used on each registration was 5.8 (4 to 7). The mean registration error was 0.75 mm (0.32 to 1.72). Neither the number of attempts for registration nor the mean registration error correlated with the number of cases carried out (Fig. 5).

The mean time required to insert the screws after surgical exposure was 38.45 minutes (20 to 70), and the mean time required to insert each screw 6.6 minutes (3.3 to 12.5).
The instrumentation time was longest during the first two cases in this series.

In one patient, an expansion of two pedicles was detected by palpation after decompression. This was in a 71-year-old woman with L3/L4 and L4/L5 listhesis, spinal stenosis, scoliosis and marked osteoporosis with narrow pedicular diameters. Screws were placed in the L3, L4 and L5 pedicles using the frameless stereotactic image guidance. After drilling, the correct direction of the holes and the integrity of the pedicle cortex were assessed with the intrapedicular sharp probe and a blunt ball-tip probe. Screws of 5.5 mm diameter were placed in the L3 and L4 pedicles. The L4 screws, however, were palpably loose and were exchanged for screws of 6.5 mm diameter. Once the decompression had been carried out, an expansion of both L4 pedicles was detected on palpation with the blunt probe. No impingement of the nerve root was noted and the screws were left in place.

The 35 postoperative CT studies analysed the levels L1 (2 screws), L2 (8 screws), L3 (16 screws), L4 (51 screws), L5 (54 screws) and S1 (40 screws). In three patients, changes in the intraoperative EMG were noted during the placement of the screw. Postoperative CT, however, confirmed their correct placement (Fig. 6). In two patients with narrow pedicles, three screws had penetrated the lateral wall. No medial or inferior walls were penetrated in any case.

The statistical analysis of our data, using 95% confidence intervals, indicates a risk of medial and inferior screw penetration of less than 0.02% with this method of stereotactic image-guided insertion of the pedicle screws. There was no case of clinically apparent neurological complication. One patient had a deep wound infection which responded to surgical debridement and antibiotic therapy.

Discussion

Pedicle screws in the lumbar spine have been shown to be an effective method of instrumentation. Since the pedicles are intimately related to the theca, nerve roots can be injured by violation of the medial or inferior cortex. In 1987, the Scoliosis Research Society reported an incidence of 3.2% of nerve damage after the use of pedicle screws, and West, Ogilvie and Bradford in 1991 described an incidence of 2% of nerve damage associated with misplaced pedicle screws.

Intraoperative radiography and C-arm fluoroscopy have been used to define anatomical orientation before a screw is placed. Even with this technique, Castro et al reported an incidence of 40% of misplaced screws.

Frameless stereotaxy for intracranial surgery has been used since 1986. The first laboratory experience of the use of this procedure in the spine was reported in 1995. The major difficulty in adapting the stereotactic principle to spinal surgery was to identify a frame of reference. The Stealth Station eliminates the need for a frame-based system by using a reference arc consisting of a bone clamp fitted with LEDs attached to a fixed skeletal structure such
as a spinous process. The anatomy of the spine is ideal for stereotactic applications because the vertebral segments have numerous anatomical landmarks which are easily distinguishable and can be used as fiducial points of reference. The use of LEDs on the surgical instruments makes it possible to track specific points on the instrument in space and allows ‘freehand’ surgical navigation. This is an immediate process as opposed to the more time-delayed concept of traditional stereotactic systems.

Our initial results indicate that frameless stereotactic image guidance is a safe and effective system for transpedicular screw placement in the lumbar spine. It allows insertion of screws in a timely fashion and it does not require a lengthy learning curve.

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References