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Verification of the position of pedicle screws in lumbar spinal fusion

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Abstract Medial or lateral pedicle screw penetration with the potential to affect neural structures in a well-known and frequent problem associated with posterior spinal fusion. We evaluated the placement of pedicle screws ($n = 141$) in 36 patients following posterior lumbar spinal fusion with Socon or Kluger instrumentation via a lateral transpedicular approach. The examination was based on CT and MR images performed after removal of the instrumentation, on average 1 year after implantation. We found seven pedicle screws with lateral cortical penetration of the pedicle and five screws with medial cortical penetration of the pedicle (8.5% pedicle penetration overall). No severe radicular complications accompanied these pedicle

penetrations. The mean insertion angles of the pedicle screws at the L4 level were 22.6° and 23.1° for the left and the right side, respectively. At the L5 level the mean insertion angle was 20.5° on the left side and 21.5° on the right, and at the S1 level the mean angle was 16.2° on the left and 15.2° on the right. The results of this study indicate that the lateral transpedicular approach is a safe procedure for pedicle screw insertion.

Key words Pedicle fixation · Posterior spine surgery · Lumbar spine · Complications

Introduction

Implantation of pedicle screws in lumbar spinal fusions is a sophisticated surgical technique, with penetration of pedicles by the screws being one of the major complications. One study indicated a 40% incidence of pedicle penetration in a lateral or medial direction [7]. Several authors in the last two years have reported on pedicle screw misplacement [4, 14, 18]. Conventional radiography is insufficient to evaluate the accuracy of pedicle screw placement. In a study by Farber et al., CT scans showed ten times more screws penetrating the medial or lateral cortex of the pedicle than did plain radiographs and five times more screws penetrating the anterior cortex of the vertebral body [5]. The reported rate of transient neuropraxia is

2.4%–3.5%. The incidence of permanent root injury is reported to be between 1.5% and 3.2%. It is important to emphasize that, in most studies, the rate of pedicle screw misplacement is higher than the rate of transient or permanent neurological deficit.

One of the main problems in surgery is that the two-dimensional fluoroscopic control used during pedicle screw insertion only enables visualization of pedicle screw placement in the sagittal plane. Therefore, a special computerized guide for pedicle screw placement has been developed [12].

The purpose of this study is to review pedicle screw positions and proven damage to a nerve root due to screw placement in patients having undergone lumbar spinal fusion via a lateral approach [9, 15, 16]. Additionally, the ideal insertion angles for the screw placement from L3 to S1 using this approach are given.

Patients and methods

We evaluated the placement of pedicle screws ($n = 141$) in 36 patients (22 male, 14 female) with an average age of 47.3 years (range 22–59 years) using CT and MRI. These scans were performed routinely, either after removal of the instrumentation (18 cases) or to re-evaluate the patient at a 2-year follow-up (18 cases). Screw holes in the vertebral bodies can be clearly seen on CT and MRI once the disturbing metal artefacts are removed with extraction of the instrumentation (Fig. 1). In our clinic removal of the device after dorsolateral fusion is common to avoid complications due to screw loosening, breakage or soft tissue irritation. The instrumentation is not removed when an interbody fusion is performed concurrently.

The CT scans that were performed after metal removal used a standardized protocol with 3-mm thick slices, so that the screw holes could be seen clearly. The other CT and MRI scans did not always show the pedicle screw holes on both sides, depending on the gantry level. Therefore, only 141 pedicle screw holes were available for examination and measurement (Fig. 2).

Fig. 1 Metal artefacts on a CT scan performed with implants in the vertebral body

Fig. 2 CT scan of pedicle screw holes without any artefact, after removal of implants

In our patients dorsolateral fusion had been performed either because of failed back surgery ($n = 29$), mostly after disc herniation, or spondylolisthesis ($n = 7$). We used a standard midline posterior approach for device implantation. The point of entry in the lumbar spine is located at the intersection of the lines bisecting the transverse process and the lateral border of the superior articular process (the “nape of the neck” of the superior articular facet, after Weinstein [16]). A Steffee dissector alone was used to perforate the cortex and the pedicle under lateral plane image intensifier control. The screws were inserted manually into the vertebral body, 15° – 25° to the sagittal plane, to a depth of about 80% of the vertebral body diameter. In some cases at the S1 level, the screws were inserted into the ventral cortex of the sacral bone. Two investigators evaluated the placement of the pedicle screws and determined the angle of pedicle penetration to the sagittal plane. In addition we looked for ventral penetration of the vertebral body as well as medial or lateral pedicle penetration. In 3 cases we implanted a Kluger fixator and in 33 cases a Socon fixator. For fixation we used 6-mm screws in all cases.

Results

We performed screw fixation at the L3 level in only two cases. The angles on both sides were 29° to the sagittal plane. No pedicle or vertebral body penetration was observed. In 23 cases we performed screw fixation at the L4 level. Here the average angle to the sagittal plane was 22.6° (range 14° – 32°) on the left side and 23.1° (range 16° – 34°) on the right side. In five cases the vertebral body was perforated ventrally without vessel injury. In six cases the pedicle was penetrated laterally without cortical fragments and without proven damage to a nerve root. The mean angle of these six pedicle screw holes was 20.6° . One case of medial penetration without cortical fragment or proven nerve root damages with an angle of 28° was observed (Fig. 3).

We performed screw fixation at the L5 level in 13 cases. The average angle of pedicle screw placement using the lateral approach was 20.5° (range 10° – 27°) on the left side and 21.5° (range 14° – 28°) on the right. Lateral pedicle penetration occurred twice, at an angle of 16° (Fig. 4). Penetration of the ventral vertebral cortex without vessel injury could be seen in two cases.

In 33 cases we performed screw fixation at the S1 level. Only 32 cases could be evaluated on the left side due to poor visualization of one level in the MRI study. The angle of insertion with respect to the sagittal plane was 16.2° (range 8° – 22°) on the left side and 15.2° (range 4° – 22°) on the right. Here we observed a medial penetration of the pedicle in two cases, at angles of 40° and 22° , respectively. However, here too no damage to the nerve roots was apparent. Ventral penetration of the sacrum occurred in ten cases, without vessel injury.

There was no significant difference between the results of the two investigators who evaluated the CT scans. Overall, the rate of medial or lateral pedicle penetration was 8.5% (12 of 141); the ventral body was perforated in 11.3% of cases (16 of 141). The pedicle screws showed no more than 3 mm penetration in either a medial or lateral

Fig. 3 A medial pedicle penetration demonstrated on CT scan. (The image is from a cadaver study, as in our patients penetration was less than 3 mm in all cases)

Fig. 4 A lateral pedicle penetration demonstrated on CT scan

direction. Using intraoperative fluoroscopy, we did not observe foraminal intrusions.

Discussion

Our data indicate that 91.5% of the pedicle screws were inserted correctly into the pedicle, and that the remaining 8.5% penetrated the medial or lateral border of the pedicle by 3 mm or less. Gertzbein and Jerosch extrapolated a "safe zone" of 0–4 mm in relation to the intradural contents, since anatomical dissections have shown that there

is 2 mm of epidural space in the lumbar spine, with another 2 mm of subarachnoid space from T10 to L4 [6, 7]. Encroachment on the lateral recess has been considered safe for nearly the same distance. Neurological deficits after lateral pedicle penetration are rare. Other complications, such as epidural hematomas, may be responsible for transient or permanent nerve root affection.

The need to choose the right entry point for the approach to the pedicle has been discussed in detail. The correct insertion angle has been described to be between 10° and 20° in the thoracic and lumbar spine. Only at the L5 level should the angle of insertion be higher, usually about 25° [14]. However, individual characteristics of pedicle anatomy have to be respected [8, 14]. In our department, the lateral approach described by Magerl and Weinstein is used [9, 15, 16], so the angles may be somewhat greater. This approach reduces interference with the upper uninvolved lumbar motion segment. The preferred entrance is at the lateral and inferior corner of the superior articular facet, which allows the pedicle screw to penetrate deeper into the vertebral body.

Roy-Camille described a sagittal approach to the pedicle using a medial entry point [10]. The problem with this approach is the risk of lateral pedicle perforation and, since the distance that the pedicle screw can be inserted into the vertebral body is shorter, the pedicle screw may loosen earlier.

Nerve root damage cannot be excluded even if the accuracy of pedicle screw placement is very good. The Scoliosis Research Society reported a 3.2% rate of neural deficit in all procedures involving pedicle screw placement [2], West et al. reported a rate of about 7% in a study of 61 patients and Boos et al. a rate of about 4% in a study of 50 patients [1]. Esses et al. reported on 617 patients in whom pedicle screw fixation was performed. In all, there were 3949 pedicle screws used, and screw misplacement was observed in 32 patients. The authors pointed out that the cases of screw misplacement included only those in which inaccurate screw positioning was noted after surgery. They also described 15 cases (2.4%) of transient neuropraxia and 14 cases (2.3%) of permanent root injury. Yuan et al. reported on 2177 cases of pedicle screw fixation in patients with degenerative spondylolisthesis [18]. They observed that approximately 5% of the patients had intraoperative events associated with the use of pedicle screws. However, events such as nerve root injury, spinal cord injury, and vascular injury occurred infrequently, with an incidence of less than 1%. Vertebral body penetration and dural tears caused by the screws occurred in less than 0.5% of cases. However, the authors could not relate these events to inaccurate screw positioning. In a review article Vaccaro et al. reported that in a study on Whitecloud et al. a 45% overall rate of minor and major complications was observed [14]. Nerve root irritation from misplaced screws was seen in two patients (5%). In the same article, Vaccaro et al. referred to a report by West et

al. of 36 misplaced pedicle screws in 124 cases evaluated postoperatively by radiography. Of this total of 36 misplaced pedicle screws, only 2 were accompanied by neurological impairment. Davne and Myers reported neural injury in 1.1% of patients (out of 533 procedures), with only two screws (0.4%) partially outside the pedicle, displacing the nerve [2]. However, it is difficult to evaluate the accuracy of pedicle screw positioning relying solely on plain radiographs. Farber et al. reported finding about ten times more instances of pedicle perforation on CT scans than on plain radiographs, and five times more screws penetrating the anterior cortex of the vertebral body [5]. Thus, the reported rates of pedicle screw misplacement are comparable only for those studies in which CT scans were used.

We agree with Farber and Esses [4, 5] that with greater surgical experience and shorter operative times the reported incidence of deep infection, and in our opinion even the reported rate of complications, due to pedicle screw misplacement, is decreasing to levels comparable with other forms of internal fixation in the lumbar spine. We do not agree with these authors' suggestion that there has to be less reliance on radiographic assistance to shorten operative times. We prefer to insert pedicle screws under fluoroscopic control to prevent foraminal intrusion – probably the highest potential risk for nerve root damage.

In our study, ventral cortical penetration of the vertebral body was documented in 12 cases. The cause of ventral perforation is usually the wrong choice of pedicle screw length. A potential problem related to anterior perforation is that the tip of the pedicle screw may injure the big vessels in front of the vertebral column [3]. In our study we did not observe vessel injury. In screw insertions into S1, we sometimes penetrate the ventral cortex to increase stability if the bone appears fragile.

Conclusion

The transpedicular approach for internal fixation of the spine is a difficult procedure that should be performed by experienced surgeons. Cadaver studies should be carried out in special instructional courses before performing this procedure on patients. If radicular nerve root symptoms appear within a short time interval after surgery, CT may reveal pedicle screw misplacement. Therefore, CT scanner software that can eliminate metal artefacts is necessary. Further investigation has to be done to ascertain the biomechanical impact of pedicle screw misplacement.

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