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Laboratory Investigation

Pedicle Screw Placement in the Thoracolumbar Spine Using a Novel, Simple, Safe, and Effective Guide-Pin : A Computerized Tomography Analysis

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Objective : To improve pedicle screw placement accuracy with minimal radiation and low cost, we developed specially designed K-wire with a marker. To evaluate the accuracy of thoracolumbar pedicle screws placed using the novel guide-pin and portable X-rays.
Methods : Observational cohort study with computerized tomography (CT) analysis of *in vivo* and *in vitro* pedicle screw placement. Postoperative CT scans of 183 titanium pedicle screws (85 lumbar and 98 thoracic from T1 to L5) placed into 2 cadavers and 18 patients were assessed. A specially designed guide-pin with a marker was inserted into the pedicle to identify the correct starting point (2 mm lateral to the center of the pedicle) and aiming point (center of the pedicle isthmus) in posteroanterior and lateral X-rays. After radiographically confirming the exact starting and aiming points desired, a gearshift was inserted into the pedicle from the starting point into the vertebral body through the center of pedicle isthmus.
Results : Ninety-nine percent (181/183) of screws were contained within the pedicle (total 183 pedicle screws : 98 thoracic pedicle screws and 85 lumbar screws). Only two of 183 (1.0%) thoracic pedicle screws demonstrated breach (1 lateral in a patient and 1 medial in a cadaver specimen). None of the pedicle breaches were associated with neurologic or other clinical sequelae.
Conclusion : A simple, specially designed guide-pin with portable X-rays can provide correct starting and aiming points and allows for accurate pedicle screw placement without preoperative CT scan and intraoperative fluoroscopic assistance.

Key Words : Pedicle screw · Guide-pin · Accuracy · Computerized tomography.

INTRODUCTION

Pedicle screw fixation is a necessary part of various spinal surgeries. Despite many advantages of using pedicle screws, their usage in the spine is replete with danger and has the potential for permanent neurologic deficit, especially when placing screws near the spinal cord at the concave apex of a scoliotic spine[5,15,16,20]. There are several methods of pedicle screw insertion that have been developed to enhance the safety of its usage. Some surgeons first identify anatomical landmarks by intraoperative C-arm image intensifier or K-wire placement into the pedicles[12,21]. Others utilize stereotactic image guided systems that are based on preoperative computerized tomographic (CT) scan or fluoroscopy[1,9,19]. The incidence of pedicle screw misplacement ranges from 2% to 44.2%, with screw-related neurologic complications in the 0–0.9% range, using the aformentioned methods[2,5-8,11,13-15,18,20-23].

Previous studies on the morphometry of thoracic pedicles indicate that there is a high inter-individual variability in the pedicle dimensions[17]. The pedicles exhibited significant variability in their shape and orientation, not only between different vertebrae within the thoracic spine, but also in the same vertebra and even in the same pedicle among individuals. Therefore, the starting point for each thoracic screw is slightly variable and is based on the anatomy of the posterior elements that are visualized intraoperatively. It is time consuming to take C-arm images after each pedicle screw placement and to rearrange the drapes each

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time an image is taken. The stereotactic image guided systems requires preoperative CT scan with exposure to high levels of radiation, higher cost, the need for expensive equipment, and prolonged operation time. Exposure to radiation is considered to be a serious health hazard[1,9,19].

To improve pedicle screw placement accuracy with minimal radiation and maintain low cost, we developed specially designed guide-pin with a ball marker (Fig. 1). We can identify the desired starting and aiming points using this guide pin. The purpose of this study was to describe a novel pedicle screw placement technique using a special guide-pin and present the results of our first 183 pedicle screw placement analyzed by CT scan.

MATERIALS AND METHODS

In the first phase, 2 thoracic spine cadaver specimens were assigned to test the accuracy of the guide-pin for transpedicular screw fixation. A specially designed guide-pin with a marker was inserted into the pedicle to identify the correct starting (2−3 mm lateral to the center of the pedicle) and aiming points (cen-

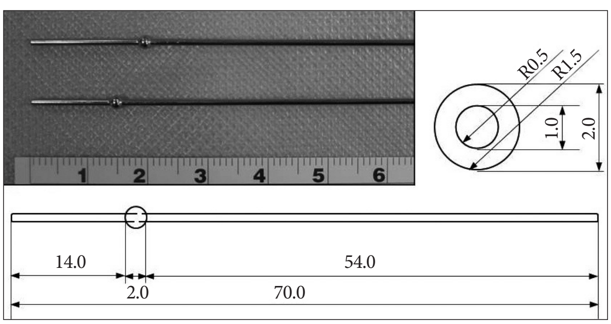

Fig. 1. Photograph (upper left) and schematic illustrations show the precise dimensions of the specially designed guide-pin with a ball maker. The guide-pin is composed of stainless steel. The guide-pin with a ball maker defines the ideal starting point by a ball marker located 15 or 20 mm proximal to the tip and the aiming spot by the tip of the guide-pin.

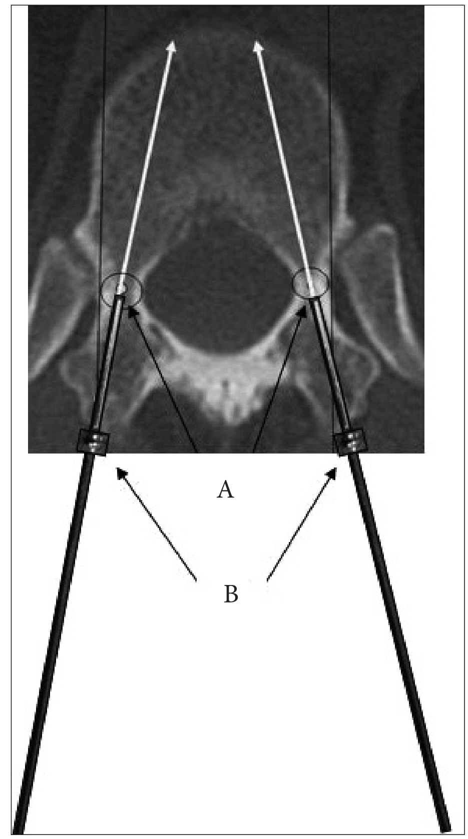

Fig. 2. A novel guide-pin was inserted into the pedicle to identify the correct starting point (A : the laminar 2–3 mm lateral to the center of the pedicle) and aiming spot (B : center of the pedicle isthmus).

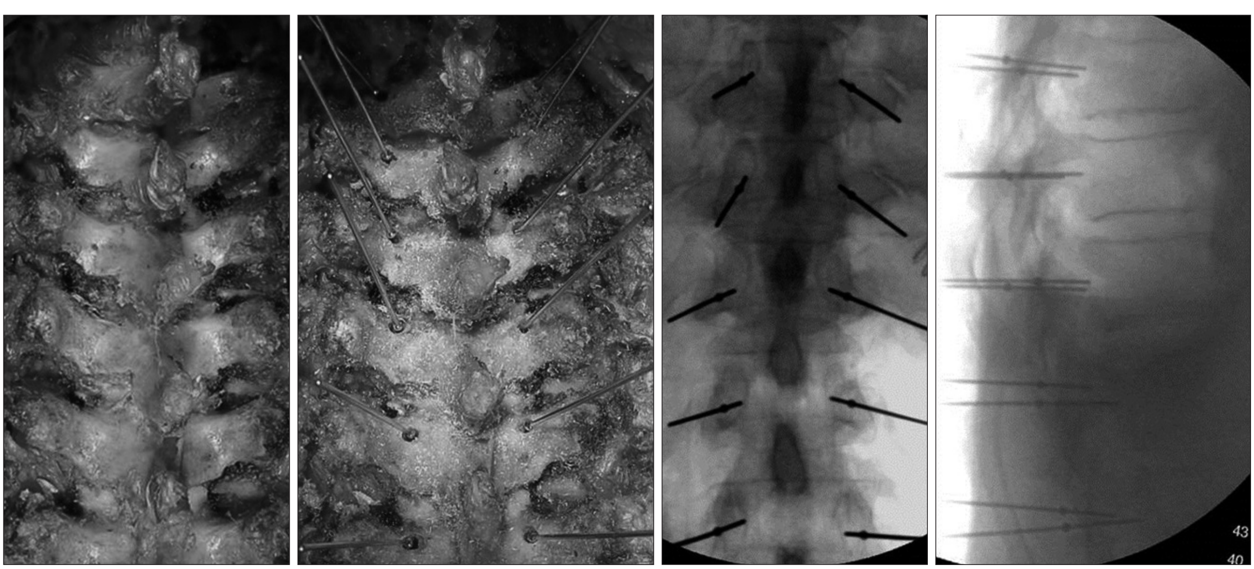

Fig. 3. Steps required for pedicle screw fixation with the specially designed guide-pin. Step 1 : complete exposure of the bony anatomy; step 2 : starting point burr (2 mm) with alleged recommendation; step 2-1 : Define the ideal starting point and aiming spot using C-arm or portable postero anterior/lateral X-rays; step 3 : the gearshift insertion according to the X-rays; step 4 : inner pedicle palpation and length measurement; step 5 : tapping and repalpation; and step 6 : screw placement slowly.

ter of the pedicle isthmus) in posteroanterior (PA) and lateral X-rays (Fig. 2).

After confirming the safety and accuracy of transpedicular screws using CT scan and naked eye examination in cadavers, eighteen patients underwent posterior stabilization utilizing transpedicular screws by two surgeons from two institutions using the same methods described above (Phase 2). All pedicle screws were inserted using the free hand technique after confirmation of the guide-pin on PA and lateral portable/C-arm images[10,11].

To objectively evaluate the position of the screws inserted, postoperative computed axial tomography (CAT) scans were performed. The relative position of the screw inside the pedicle was graded as follows : 1) contained : axis of the pedicle screw between the medial and lateral pedicle walls completely; 2) medial violation : axis of the pedicle screw is out of medial wall of the pedicle; and 3) lateral violation : axis of the pedicle screw is out of the lateral pedicle wall. The positions of the scanned pedicle screws were independently determined by two senior spine surgeons.

Surgical technique

The surgical technique of free hand transpedicular screw placement using guide-pin can be broken down into specific steps that are repeated at each level.

Incision and exposure

The first component of successful thoracic screw placement is meticulous exposure of the posterior elements. The spine was exposed to the tips of the transverse processes bilaterally, staying strictly subperiosteal to reduce bleeding. The facet joints were thoroughly cleaned of soft tissue (Fig. 3).

The placement of guide-pin using 2×15 mm cortical burring

We placed the guide-pins into the pedicles according to the recommended starting point following 2×15 mm hole by cortical burr[10]. We checked PA and lateral portable X-rays to adjust the starting and aiming points after all the guide-pins were placed (Fig. 4).

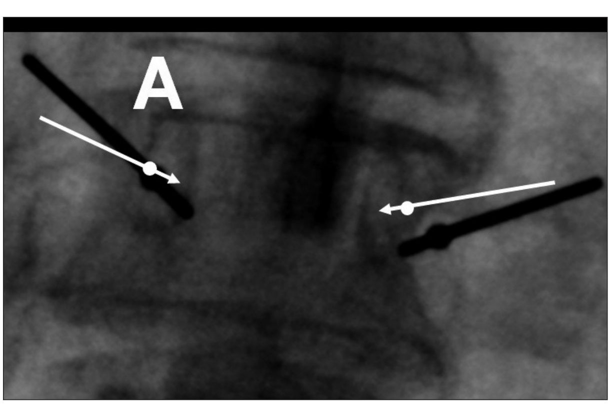

Fig. 4. Adjusting the starting point and aiming spot after complete placement of guide-pin. Guide-pin A : starting point (ball marker) looks okay (2–3 mm lateral to the center of the pedicle) but tip of the guide pin violated medial wall of the pedicle. Ideal targeting (arrows) : same starting point but near perpendicular gearshift insertion required.

Gearshift probing

We started gearshift from the dorsal lamina 2 mm lateral to the center of the pedicle. Gearshift was advanced from the desired starting point toward the center of the pedicle isthmus, which was the center of pedicle on a PA X-ray and isthmus on the lateral radiograph. After inserting the gearshift tip approximately 20 mm (past the pedicle isthmus), the gearshift was removed. We confirmed the integrity of 5 bony walls with a flexible, ball-tipped probe. The pedicle finder was then advanced further with an ultimate depth averaging 45–55 mm for the lumbar spine and 25–45 mm in the thoracic region.

Palpation and pedicle length measurement

Once the pedicle seeker was removed, the tract was visualized. A flexible ball-tipped pedicle sounding or palpating device was utilized to palpate five distinct bony borders : a floor and four walls (medial, lateral, superior, and inferior). At this point, if a soft tissue breach was palpated, this provided an opportunity to redirect the screw into an appropriate position into the pedicle.

Tapping, repalpation and screw placement

The pedicle tract was undertapped with a 1 mm less diameter tap than the intended screw. Following this, the pedicle tract was palpated again to make sure that the five osseous borders were intact. This second inspection often allowed palpation of distinct bony ridges confirming intraosseous position and the tract length was remeasured with a hemostat. The screw was slowly inserted down the pedicle into the body.

Confirmation of intraosseous screw

It is imperative that the surgeon document intraosseous placement via fluoroscopy and/or radiography. The coronal plane

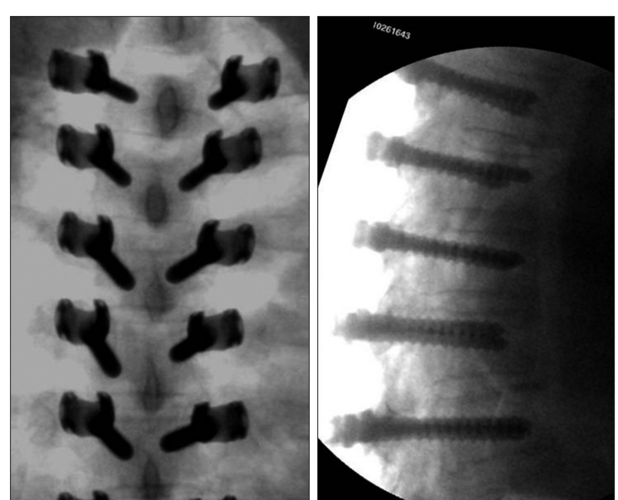

Fig. 5. Coronal and sagittal plane radiographs should confirm the harmonious position of the screws by the surgeon.

radiograph is evaluated for the harmonious position of all screws especially when any rotational scoliosis deformity exists. In cases of shorter or longer screws compared to adjacent screws, the screw length as viewed on the lateral X-ray is mandatory to check for harmonious position. On the lateral X-ray, the screws should be parallel to the superior endplates, and not extending past the anterior border of the vertebral body. These two plane radiographs should confirm the harmonious position of the screws as noted by the surgeon *in vivo* (Fig. 5).

Final instrumentation

After the insertion of the pedicle screws, deformity correction was carried if necessary. In addition, various osteotomy procedures were used depending on the etiology of the deformity. Final locking of the screws was performed after final rod placement.

RESULTS

Demographic data

There were 18 patients with a mean age of 58.2 years (range, 34–68 years) at the time of the surgical treatment. A total of 183 thoracolumbar pedicle screws were inserted. The diameter of the screws used in the thoracic spine ranged from 4.0 mm to 7.5 mm. The number of screws inserted were as follows (total n=183) : T1–6 n=28; T7–12 n=70; L1–5 n=85. The diagnoses were spondylolisthesis (7 patients), infection (3), fracture (3), spinal stenosis (3), degenerative scoliosis (1), and tumor (1).

Accuracy using CAT scan evaluation

All 183 thoracolumbar transpedicular screws inserted into the spine were evaluated by CAT scan to assess for screw position. Ninety-nine percent (181/183) of screws were contained within the pedicle. Among 183 pedicle screws inserted, thoracic pedicle screws were accurately placed in 98% by the 2 surgeons (96 of 98). Only two screws (2%) showed moderate cortical perforation which meant the central line of the pedicle screw was out of the outer cortex of the pedicle wall and included 1 screw (1%) that violated the medial wall (1 lateral violation in a patient and 1 medial violation in a cadaver specimen). Eighty-five screws inserted into the lumbar spine showed 100% accuracy without any medial or lateral pedicle wall violation.

Complications

There were no screws (out of the 135 thoracolumbar pedicle screws inserted into 18 patients) that caused neurologic or vascular complications. There were no instances of cerebrospinal fluid (CSF) emanating from the initial pedicle tract during the preparation of the screw holes. There were no postoperative CSF leaks. No pedicle screw was removed for any reason.

DISCUSSION

Pedicle screw fixation has the advantage of obtaining purchase of all three spinal columns without encroaching into the spinal canal[4]. This theoretical advantage has been translated to superior clinical results in fracture fixation as well as in deformity correction[11,15-17,20,21]. However, their usage in the spine has the potential for permanent neurologic deficit, especially when placing screws near the spinal cord at the concave apex of a scoliotic spine[3,5,15,18,23]. The safety margin for this technique has been improved through the use of image-guided techniques[1,9,19]. Nevertheless, these newer techniques require additional equipment as well as the use of fluoroscopy which increases the radiation exposure.

We developed specially designed guide-pin with a ball maker as it allows identification of the starting and aiming points as well as its direction without the problems mentioned earlier. Some surgeons identify anatomical landmarks by K-wire placement into the pedicles. The incidence of pedicle screw misplacement ranges from 1.5% to 25% using the K-wire guided methods[3,16,21]. Although previous research showed only 1.5% misplacement, they admitted that the actual rate would be higher as their patients were primarily evaluated by the postoperative radiographs[21]. Conventional K-wire guide technique could not allow direct visualization of the starting point on the intraoperative fluoroscopy and/or radiography. In the present study, only two pedicle screws of 183 (1.0%) demonstrated violations (1 lateral violation in a patient and 1 medial violation in a cadaver) as confirmed by postoperative CT scan evaluation of all pedicle screws enrolled. None of the pedicle breaches were associated with neurologic or other clinical sequelae. Our basic concept was that two points are essential to make a correct direction. One is starting point and the other one is aiming spot. The advantage of our guide-pin came from these two spots. Ball tip is corresponding to "starting point" of the dorsal cortex of the pedicle. All previous guide-pin except ours failed to show starting point. Some guide-pin had notch(es) in the middle of guide-pin but they did not demonstrate starting point. Tip of the guide-pin is placed in the isthmic part of the pedicle, which is 15 mm or 20 mm away from ball tip. The position of the tip should be located around isthmic part of the pedicle which is 15 mm to 20 mm away from starting point. This special guide-pin can show exact starting point in the dorsal cortex of the pedicle with ball tip. Also tip of the guide pin can show the exact spot around the isthmic part of the pedicle. Thus, operator can adjust the starting point and aiming spot with zero violation of the medial wall of the pedicle.

Recently, the free-hand technique has gained popularity. Kim et al.[10,11] reported a series in which 8000 screws had been placed by the free-hand technique without neurovascular complications, and only 8% had significant breaches. The free-hand technique relies on anatomy and the tactile feedback for pedicle screw insertion. We could identify the desired starting point and aiming spot using this specially designed guide-pin. Thus, we feel this novel guide-pin provides additional clinically relevant information and is helpful to the spinal surgeon to undertake pedicle screw fixation using the free-hand technique even more safely.

The weak point of this study was that confirmation of screw placement could only be performed by postoperative CAT scan and not by direct inspection in real patients. All pedicle screws inserted were titanium. Previous studies reported accuracy rates of 68% to 87% in the CT evaluation of pedicle screw placement in cadaver scans using titanium versus cobalt chrome screws[24]. Thus, we developed our simple CT criteria for violation of the pedicle wall.

CONCLUSION

A simple, specially designed guide-pin with portable X-rays can provide correct starting and aiming points to place the accurate pedicle screw without preoperative CT scan and intraoperative fluoroscopic assistance. The placement of thoracolumbar pedicle screws using this guide-pin is an accurate, reliable, and safe without increased radiation or surgical time.

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