Original Article

The influence of pedicle screw placement on thoracic trabecular strain

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Study design: Experimental study.

Introduction: Although pedicle screw loosening and fracture are not uncommon, there is little understanding of the loading relationship between the pedicle screw and surrounding bone. There is even less understanding of the trabecular bone mechanics once a pedicle screw has been removed.

Objectives: To investigate and understand the influence of the presence of pedicle screw placement and subsequent removal on vertebral trabecular strain under axial loading.

Setting: Orthopaedic Research Laboratories, University of California, Davis, USA.

Methods: Six cadaver spines were biomechanically loaded and the minimum principal and maximum shear strains were measured using texture correlation. The treatments were divided into three conditions as follows: (1) before screw placement, (2) during screw placement, and (3) after screw removal. The obtained data were statistically analyzed.

Results: Trabecular strain adjacent to the pedicle screw was increased following pedicle screw placement and remained high following pedicle screw removal.

Conclusions: The current study demonstrates that pedicle screw placement greatly influences the trabecular bone and introduces weakness in the area following screw removal.

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Keywords: pedicle screw; thoracic spine; trabecular bone; strain; biomechanics

Introduction

Pedicle screw fixation is commonly used to treat spinal injuries and disorders.^{1–6} Complications with such instrumentation, however, are not uncommon.^{7–10} More recently, compression fractures following pedicle screw removal have been reported.¹¹ These complications are attributed to two primary mechanisms: (1) implant failure or (2) bony failure. Previous pedicle screw loading studies have focused on pedicle screw loading and failure, and the pedicle screw-vertebrae complex.^{12–16} Most bony failure studies have focused on the influence of bone mineral density (BMD).^{17–20}

The specific aim of the current study is to investigate the trabecular strain behavior following pedicle screw placement. The authors hypothesized that the trabecular strain adjacent to the screw would be significantly greater than the strain of the same bone before screw placement.

Materials and methods

Six lower thoracic cadaver spines (T10–T12) were used. The average age was 75.5 years, ranging from 69 to 82 years (Table 1). The mean BMD of the thoracic specimens was 0.557 g/cm² and ranged from 0.357 to 0.654 g/cm². Each specimen was cleaned of muscle and adipose tissue. Following cleaning, the specimens were accurately sectioned to a thickness of 10-mm along the pedicular plane in a frozen state using a cryo-vise and conical grinding wheel that were set in a milling machine.^{21,22} The trabecular bone areas of the superior (T10) and inferior (T12) segments were secured and embedded in polymethylmethacrylate (PMMA; Coe Laboratories, Chicago, IL, USA). Then the molds were made to match between the exposed superior endplate of T10 and inferior endplate of T12 and the respective loading platens in PMMA.

The specimens were placed in a custom-loading frame housed in a contact radiography unit (Figure 1). Then each specimen was positioned such that the superior and inferior endplates of T11 were parallel to the loading platens (Figure 2). Compressive load was applied using

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Table 1 BMD of Global (T10–T12)

#Specimen	Age(y/o)	Gender	BMD (g/cm^2)
1	69	Female	0.548
2	59	Female	0.654
3	82	Male	0.617
4	76	Female	0.357
5	77	Female	0.640
6	79	Female	0.528

Figure 1 The custom loading frame. The specimen is fixed between upper and lower plexiglass plates to avoid out of plane bending. Radiographic film is exposed within a sliding cassette positioned under the lower plexiglass plate **Figure 2** The superior (T10) and inferior (T12) vertebrae are secured and embedded in PMMA into U-shaped loading platens **Figure 3** Three conditions: (a) before screw placement, (b) after screw placement, and (c) after screw removal

a linear stepper motor to 150 N under the following three conditions (Figure 3): (1) before screw placement, (2) following screw placement, and (3) after screw removal. Screw placement was performed with a 4.75×35 mm pedicle screw (DePuy Spine, Raynham, MA, USA) into the T11 vertebral section following a pilot hole created using a 3.0 mm drill. Each specimen was exposed at each treatment during which contact radiographs were made with the vertebral sections under loading.

Radiographs were digitized using a 16 bit digital camera (Photometrics, Tucson, AZ, USA) with a resolution of 1024×1024 pixels. The trabecular area of interest (T11) was divided into 51×41 nodes using Patran (Patran V 5.0, The MacNeal-Schwendler Corp., Los Angeles, CA, USA). The minimum principal strain and maximum shear strain were measured at each of 2091 points using texture correlation developed by Bay *et al.*²³ The spatial distribution of the trabecular strain was described using a contour plot (Delta Graph, Delta Point, Monterey, CA, USA).

The population of strains within the spatially averaged distribution was characterized by measures of central tendency and dispersion. During preliminary testing it became apparent that strain probability distributions departed from normal.²⁴ Therefore, the statistical distribution was transformed using a log-normal transformation (Stata Statistical Software, StataCorp., College Station, TX, USA). Three values were calculated: the mean (mid-range), the mean minus 1 SD (low range), and the mean plus 1 SD (high range). These values were then restored to units of strain through the inverse transform. Histograms and range values for the spatially averaged strains were examined for differences associated with boundary condition. The mean minimum principal and maximum shear strains were compared between the three conditions using a single factor analysis of variance with a level of significance of 0.05.

Results

Strain distribution

The intact specimen produced minimum principal and maximum shear strains that were mottled throughout the vertebral body, yet relatively uniform (Figure 4a).

After the specimens were inserted the pedicle screw, however, high strains were concentrated adjacent to the tip and superior aspect of the screw (Figure 4b). After screw removal, the strains were concentrated in the area created by the screw placement (Figure 4c).

Minimum principal strains

The mean high range of the minimum principal strain following screw placement and after screw removal was significantly greater than that before screw placement ($P < 0.05$, Figure 5a). There was no significant difference between the mean mid-range of the minimum principal strain among the three conditions or between the mean low range of the minimum principal strain among the three conditions.

Maximum shear strain

The mean high range of the maximum shear strain following screw placement and after screw removal was significantly greater than that before screw placement ($P < 0.05$, Figure 5b). There was no significant difference between the mean mid-range of the maximum shear strain among the three conditions or between the mean low range of the maximum shear strain among the three conditions.

Discussion

Pedicle screw fixation has been shown to be a rigid posterior construct that assists in promoting fusions of the unstable spine.¹⁻⁶ Screw breakage and loosening, however, are not uncommon.⁷⁻¹⁰ Recently, Waelchli *et al*¹¹ reported two cases of vertebral compression fractures following pedicle screw removal. Many pedicle screw loading studies have focused on pedicle screw loading and failure, and the pedicle screw-vertebrae complex.¹²⁻¹⁶ Most bony failure studies have focused on the influence of BMD.¹⁷⁻²⁰ However, no studies have

reported on the change in the trabecular bone loading during screw placement or following pedicle screw removal.

Figure 5 (a) Minimum principal strains and (b) maximum shear strains of the three conditions at 150 N. Bars illustrate the average low, mid, and high range values for the six samples

Figure 4 Contour plots of the three conditions of the Specimen No. 4: (a) before screw placement, (b) after screw placement, and (c) after screw removal. Each is scaled to the same range shown in the right

Routine implant removal following general fracture healing is still somewhat controversial due to the perceived risks and benefits.^{25–28} Late infection, metal toxicity, and metal hypersensitivity may develop in cases of retained implants.^{28–31} In younger spine patients, implant removal is relatively common. In support of this surgical practice, vertebral osteopenia thought to be associated with stress shielding has been reported in cases of instrumented spinal fusion.^{32,33}

The current study investigated the influence of pedicle screw placement and removal on vertebrae trabecular strain using texture correlation.²³ Previous studies have reported trabecular strain values using finite element models.^{34–36} The study incorporated an experimental technique that allows for extremely accurate and direct measurements of trabecular strain.^{21,22} The study showed that the trabecular strain significantly increased following screw insertion, and remained high following screw removal. These results demonstrate that pedicle screw placement greatly influences the trabecular bone strain and introduces a weakness in the area after screw removal.

One of the limitations of the current study was that the ribs were removed before testing. The current study was not designed to quantify the actual strains that may occur in the thoracic spine, but to provide the relative changes to the thoracic trabecular strain with pedicle screw placement and removal. Therefore, rib removal was not believed to affect the relative changes that are reported in the current study. Another limitation was that the specimens were somewhat older than the typical patient who undergoes pedicle screw fixation. It would be expected that younger specimens with higher BMD would have lower strains for a given load, but the relative changes would be similar to those presented in the current study. With the exception of one specimen, the specimens had similar BMDs. Since each specimen was used as its own control, this variability in BMD did not play a substantial role in the study since all treatment measurements were compared to those of the intact control. In addition, some of the specimens in the current study had osteophytes, but again, the relative changes that occur with and without pedicle screws are still present regardless of the number of osteophytes present. Finally, it is well understood that pedicle screw removal would typically take place after a fusion mass had formed and, as described above, the current experimental model does not fully represent the *in vivo* case. The model, however, was developed to focus on the interaction between the thoracic trabecular bone and the implanted pedicle screws.

Instrumented spinal fusion patients often wish to have their instrumentation removed following a successful fusion because of mild local discomfort, such as back pain or stiffness. The current results, however, demonstrate that the local trabecular region following screw removal is significantly weaker than was once thought. This weakened bone must be taken into account when performing pedicle screw removal. Augmenting the hole with cement or bone after screw removal is not common.

One possible method augmenting this void may be through a technique similar to that used in percutaneous transpedicular vertebroplasty.^{37–40} Augmenting the void with a bone filler such as an autograft, allograft, or calcium phosphate cement may be considered to prevent subsequent compression fractures. The effect of this filler could also be tested using the techniques described in the current study and well as ultimate strength testing.

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