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Percutaneous Pedicle Screw Fixation with Vertebral Augmentation Using a Bioengineered Degradable Bone Substitute for Thoracolumbar Fractures

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Study Design: Retrospective analysis.
Objectives: The study evaluated the technical aspects of percutaneous pedicle screw fixation (PPF) and vertebral augmentation (VA) with bioengineered degradable bone graft substitutes (bd-BGs) using the trans-pedicular approach in a single surgical procedure.
Summary of Literature Review: The effectiveness of PPF with VA using bd-BGs for thoracolumbar fracture has not been established.
Materials and Methods: We enrolled 17 patients diagnosed with acute thoracolumbar fractures who underwent simultaneous PPF and VA using bd-BGs. The short-segment PPF construct included the adjacent vertebra immediately above and below the fractured vertebra, in addition to intermediate screws for the fractured vertebra. The posterior instrumentation was removed at least 9 months after surgery from patients in whom bone union was confirmed by computed tomography. The sagittal Cobb angle and visual analogue scale (VAS) were used to evaluate clinical outcomes.
Results: The mean age of the patients was 62.12±8.18 years. All patients were followed up for at least 12 months after the index surgery, with the mean follow-up period being 14.8±3.32 months. The volume of injected bd-BGs was 3.84±0.19 mL. VAS scores significantly improved 2 weeks after surgery (p<0.001). The sagittal Cobb angle was realigned from an average preoperative value of 26.68±3.93° to 2.86±4.90° post-surgery (p<0.001). bd-BGs leakage was observed in the adjacent superior disc in two patients and an increasing kyphotic angle due to a lower-most instrumented vertebra fracture was observed in one patient. However, there was no significant fixation failure or vertebral re-collapse.
Conclusions: PPF with VA using bd-BGs is technically feasible and may be a simple, effective, and less-invasive treatment for thoracolumbar injuries.

Key words: Thoracolumbar fracture, Percutaneous pedicle screw fixation, Vertebral augmentation, Bioengineered degradable bone graft substitute, Calcium-based bioactive ceramics

Introduction

Thoracolumbar fracture can cause devastating injuries with or without neurologic deficits. The surgical goals in thoracolumbar fracture include correction of kyphotic deformity, maintenance of initial stability and alignment, direct and indirect decompression of neural elements, minimization of the requirement for external immobilization, and promotion of early ambulation and rehabilitation. In this regard, short segment posterior lumbar instrumented fusion (PIF), consisting of trans-pedicular screw fixation one vertebra above and below
the fractured vertebra, has been recognized the standard procedure for thoracolumbar fractures. Nevertheless, PIF has been associated with high surgical site infection rates and blood loss, prolonged operation time, and long hospital stays. Above all, the level of trauma inherent to PIF can lead to persisting sequelae, including paravertebral muscular denervation, atrophy, and pain. However, percutaneous pedicle screw fixation (PPF) has emerged as an alternative, minimally invasive surgical procedure to reduce the trauma in paravertebral musculature and to preserve the soft tissue connections, vascularity, and fracture hematoma, notwithstanding concerns about inadequate reduction of vertebral height. Significant initial vertebral height loss is known as an independent predictor of re-collapse after PIF. Vertebral augmentation (VA) with calcium-based bioengineered degradable bone graft substitutes (bd-BGs) may reinforce thoracolumbar fracture stability, partially restore vertebral height, and reduce pedicle screw bending and movement. Because of the similar transpedicular approaches for PPF and VA, they can be performed simultaneously in one surgical process. However, it is unknown as to whether the combination would constitute a simple, less invasive, motion-preserving technique.

Therefore, we recorded the clinical and radiological outcomes and presented the technical aspects of performing PPF and VA with bd-BGs, using the same percutaneous trans-pedicular approach in one surgical procedure.

Materials and Methods

This study was approved by the Institutional Review Board (IRB number: 2019-08-014). Informed consent was obtained from all patients.

1. Study design

Seventeen patients who simultaneously underwent PPF and VA with calcium-based bd-BGs (PRO-DENSE™, Wright Medical Technology, Arlington, TN, US) were enrolled in this retrospective study from January 2018 to January 2019. All patients were diagnosed with acute thoracolumbar fractures (AO/Type A – vertebral split fracture; A3– incomplete burst fracture; B1– transosseous tension band disruption/Chance fracture; B2– posterior tension band disruption) without neurological deficits and were operated within two days after trauma, and only one case underwent surgery 4 weeks after trauma due to medical condition. The exclusion criteria were as follows: polytraumatized patients, patients with spinal deformities, previous vertebral fractures, infective spondylitis, inflammatory spondylitis, and previous spinal operations.

2. Patient population

There were six men and eleven women, ranging from 48 to 82 years of age (average, 62.12±8.18 years) at the time of surgery. The mechanism of injury was fall from their own height in eleven patients, falling on stairs in three patients, and traffic accidents in three patients. Neurologic assessment was made in each patient using a rating system based on the American Spine Injury Association (ASIA) impairment scale, and Tholacolumbar Injury Classification and Severity (TLICS) score was evaluated. (Table 1). Regarding back pain, postoperative pain intensity was recorded on the Visual Analogue Scale (VAS). The sagittal Cobb’s angle (the angulation between upper endplate of two level above vertebra and lower endplate of two level below vertebra from the fractured vertebra) and anterior vertebral height were measured on lateral plain radiographic images prior to and after surgery (Table 2).

3. Surgical procedure

All surgical procedures were performed with the patients under general anesthesia with endotracheal intubation. Patients were placed in a prone position on a Wilson frame on a radiolucent operating table. The subjects of this study were fractures with a score of less than six point of the McCormack load sharing classification and were able to achieve fracture reduction and stabilization with a short-segment posterior approach with pedicle screw fixation without the need for corpectomy. The short-segment PPF construct included the adjacent vertebra immediately above and below the fractured vertebra plus intermediate screws for the fractured vertebra. To obtain the standard AP view, we placed the C-arm perpendicular to the longitude of the operating table and floor and then slightly rotated the patient until images of the spinous processes
could be obtained completely bisecting the pedicles. Then, considering lumbar lordosis, the position of the C-arm was adjusted until the anterior and posterior endplates of the segment appeared identical. A targeting cannulated needle for each pedicle of the instrumented adjacent vertebrae was used for initial insertion into the stab wound to locate the pedicle using the 3 or 9 o’clock method. Six K-wires were then passed through the needle, and all additional instruments and screws were taken from the guide wire. Poly-axial, fully cannulated pedicle screws (Viper 3D MIS correction system, Depuy–Synthes Spine, MA, US) were placed with extender sleeves down into the pedicles of the nonfractured vertebrae above and below the fractured vertebra, with subsequent removal of all 4 K-wires. Selecting the appropriate rod length with rod calipers and appropriate contouring of the rod, it was inserted through the end screw extender sleeve (end vertebra) and the position was controlled using an image intensifier. Reduction of the rod into the screw tulip was finally done using a reducer. Then, we tightened the inner set screw at the bottom pedicle screw and attached the distraction rack of the Viper 3D MIS correction system to restore the fractured vertebral height. When proper reduction of vertebral height was confirmed under C-arm fluoroscopy, a trocar for vertebral augmentation was inserted along the K–wire into the fractured vertebra; subsequently, calcium sulfate/phosphate cement was injected under real-time fluoroscopic imaging to perform vertebral augmentation. After the final pedicle screw was inserted, percutaneous pedicle screw fixation with an intermediate screw was performed in the same way (Fig. 1).

Table 1. Demographic data

|                |       |
|----------------|-------|
| Age (year)     | 62.12±8.18 (48-82) |
| Gender         | 6 male, 11 female |
| Body mass index (kg/m²) | 24.72±2.41 |
| Injury mechanism |       |
| Falling above their own height | 11 |
| Falling on stairs | 3 |
| Traffic accident | 3 |
| Fracture level |       |
| T11            | 3     |
| T12            | 7     |
| L1             | 5     |
| L2             | 2     |
| American Spine Injury Association (ASIA) scale |       |
| D              | 4     |
| E              | 13    |
| Thoracolumbar Injury Classification and Severity (TLICS) Score |       |
| Morphology     | 2.35±0.78 (2-4) |
| Posterior ligamentous injury | 1.82±0.95 (0-3) |
| Neurologic deficit | 0.47±0.87 (0-2) |
| Total          | 4.64±1.22 (4-7) |

*Values are presented as mean±standard deviation.

Table 2. Clinical and radiological outcomes

|                        | Clinical Outcomes | Radiologic Outcomes |
|------------------------|-------------------|---------------------|
|                        | VAS               | p-value       | Sagittal Cobb’s angle | p-value | Anterior vertebral height | p-value |
| Preoperative           | 8.11±0.49         | <0.001        | 26.68±3.93            | <0.001  | 14.14±3.45                 | <0.001  |
| Immediately postop     | 3.14±0.90         | <0.001        | 2.86±4.90             | <0.001  | 27.13±1.01                 | <0.001  |
| Postoperative 2 weeks  | 2.22±0.81         | <0.001        | 3.78±4.68             | <0.001  | 26.63±1.54                 | <0.001  |
| Postoperative 6 weeks  | 2.14±0.90         | <0.001        | 5.65±8.74             | <0.001  | 25.75±3.03                 | <0.001  |
| Postoperative 3 months | 1.43±1.13         | <0.001        | 8.05±9.71             | <0.001  | 25.68±3.18                 | <0.001  |
| Postoperative 6 months | 1.29±0.49         | <0.001        | 8.08±9.72             | <0.001  | 25.68±3.18                 | <0.001  |
| Postoperative 12 months| 1.33±0.81         | <0.001        | 8.17±9.71             | <0.001  | 25.72±1.84                 | <0.001  |

*Values are presented as mean±standard deviation. The statistical significance was set at p<0.05. VAS: Visual Analogue Scale
4. Postoperative care

Patients were encouraged to walk wearing a custom-made brace from the day after surgery, for 6 weeks. Vigorous work and activity were restricted up to 12 weeks after surgery. Subsequently, unrestricted activity was permitted depending on the individual neurologic situation. Nine months after surgery, bone union of vertebral fractures was evaluated by computed tomography in all patients, and in patients with confirmed bone union, the posterior instrumentation was removed. At least three months after the removal of posterior instrumentation, a plain radiography was performed for the follow-up of all patients.

5. Statistical analysis

Statistical analysis was performed using Student’s t-test for changes in each radiographic parameter and clinical outcomes. Values of p<0.05 were considered statistically significant. Statistical analyses were performed using SPSS 20.0 (IBM Corporation, Armonk, NY, USA).

Results

All patients were followed up for at least 12 months.
after the index surgery. The mean follow-up period was 14.8±3.32 months. The average operative time was 48 ±20.3 minutes (range, 40~70 minutes) (Table 3). The patients experienced back pain improvements immediately after surgery, and 2 weeks after surgery the mean VAS score significantly dropping from 8.11±0.49 to 2.22±0.81 (p<0.001). And this improvement of VAS score lasted until 12 months after surgery. There were no neurological complications or revisional surgeries due to wound infection or fixation failure during hospitalization and the follow-up period.

An analysis of the sagittal Cobb’s angle, measured in

| Table 3. Operative data |
|-------------------------|
| Mean follow-up period (months) | 14.8±3.32 (at least 12 months) |
| Operation time (minutes) | 48±20.3 (40-70) |
| Length of hospital stay (days) | 7.16±2.83 |
| Injected bd-BGs volume (mL) | 3.84±0.19 (3-4) |
| bd-BGs leakage (N) |
| Intradiscal | 2 |
| Lateral or anterior cortex | 0 |
| Posterior canal | 0 |

*Values are presented as mean±standard deviation. bd-BGs: bioengineered degradable bone graft substitutes. 

Fig. 2. A 70-year-old male patient suffered severe acute back pain caused by rolling down the stairs. (A) Plain radiographs, (B) Contrast-enhanced magnetic resonance imaging tests diagnosed acute T11 incomplete burst (AO A3) fracture with a suspicious posterior ligamentous complex injury. (C) He underwent percutaneous pedicle screw fixation of T10-T11-T12 with vertebral augmentation using a calcium-based degradable bone substitute. (D) At an outpatient follow-up visit 5 weeks after surgery, he suffered recurrent back pain, and on follow-up plain radiographs, trace height loss of the 11th and 12th thoracic vertebrae and an increase in the sagittal Cobb angle (CA) were observed (preoperative CA: 30.14°, postoperative CA: 11.12°, 6-week postoperative CA: 22.18°, 3-month postoperative CA: 24.62°). Three months after surgery, the axial back pain improved and the kyphotic deformity was no longer observed to be advanced on a radiological examination.
plain lateral radiographic images before and after surgery, confirmed the excellent fracture reduction in most patients. Sagittal Cobb’s angle was corrected from an average preoperative value of 26.68±3.93 degree to 2.86±4.90 degree after surgery (p<0.001). The mean sagittal Cobb’s angle was 8.17±9.71 degree 12 months after surgery. Anterior vertebral height was recovered from an average preoperative value of 14.14±3.45 to 27.13±1.01mm after surgery (p<0.001). The mean anterior vertebral height was 25.72±1.84 mm, 12 months after surgery (Table 2). Only one patient showed an increased kyphotic angle due to a lower-most instrumented vertebra fracture. However, there were no significant fixation failures or vertebral re-collapses (Fig. 2).

The volume of injected bd-BGs was 3.84±0.19 ml (range, 3~4 ml). bd-BGs leakage was observed to the adjacent superior disc in two patients, without clinical sequelae (Table 3). The radiopacity shading of the bd-BGs started to decrease at 6 weeks postoperative x-ray, and was mostly disappeared at 12 weeks postoperative x-ray.

A follow-up computed tomography conducted nine months after the surgery showed that all patients had bone union. After an average of 10.6±1.70 months, posterior instrumentation was removed from all patients. After removal of posterior instrumentation, no clinical relapse of axial back pain or significant change of the sagittal Cobb’s angle in plain lateral radiograph was observed and the movement of the spine segment that was previously fixed could be observed (Fig. 3).

**Discussion**

This study aimed to demonstrate the technical aspects and clinical outcomes of PPF and VA with bd-BGs using the same trans-pedicular approach in a single surgical procedure. After surgery, a significant improvement in back pain and restoration of sagittal cobb’s angle were observed, and no significant fixation failure or vertebral re-collapse was noted during the follow-up period. According to previous retrospective study of unstable

![Fig. 3. A 51-year-old woman was diagnosed with a T12 incomplete vertebral burst fracture with posterior ligamentous complex injury. Computed tomography conducted before (A) and 9 months after surgery (B) showed vertebral bone healing, and posterior instrumentation removal was performed 11 months after surgery. Reduction loss was not observed when compared with the lateral plain radiographs conducted before (C) and after (D) posterior instrumentation removal at 11 months after surgery. There was intersegmental motion that had been fixed in the flexion (E) and extension (F) dynamic radiographs at 15 months after surgery.](image-url)
Thoracolumbar burst fractures in 19 patients with posterior instrumentation with trans-pedicular vertebral augmentation using calcium sulfate/phosphate-based bone cement, the clinical outcomes after surgery were significantly improved in all patients, and this is similar to the results of our study. Also, during the follow-up period, the correction loss angle was reported to be 3.9 degree and it was found to be 5.4 degree in our study. It is thought that this is because the correction loss was reflected in one case of lower-most instrumented vertebral fracture was induced, and the average correction loss angle excluding this case was 4.0 degree. Therefore, the results of this study are similar to those of the previous report, and it is thought that early union and good clinical outcomes can be obtained in thoracolumbar burst fracture through PPF and VA with bd-BGs technique.

The vertebral fracture remodeling process is physiologically complex, involving both biological and mechanical properties. Repair of vertebral fractures is generally performed along with indirect (secondary) bone healing. Generally, indirect bone healing consists of both endochondral and intramembranous bone healing through acute inflammatory response, recruitment of mesenchymal stem cells, generation of cartilaginous callus, revascularization, mineralization of the callus, and bone remodeling. This is the theoretical background of biological fracture healing in intramedullary nailing and bridge plating, including minimally invasive plate osteosynthesis for long bone fracture. Most importantly, a key-point of biologic fracture healing is achieving stability of the construct by intramedullary nailing and bridging the locking plate-screw system that allows micro-motion of the fracture site. From this point of view, vertebral bone remodeling is thought to the most important aspect in stability of the construct. Nevertheless, because of the presence of intervertebral discs in the functional spinal unit, posterior intersegmental fixation cannot achieve complete bony continuity. Therefore, posterior intersegmental fixation for vertebral fracture remodeling needs to be more rigid than in the intersegmental fixation for lumbar interbody fusion surgery.

In this regard, longer posterior intersegmental fixation, attached to a greater number of vertebrae, reduces forces acting on the pedicle screw because of the effect of the greater lever arm of a longer rod, ultimately allowing only limited motion in the fracture site. A longer fixation is biomechanically advantageous; however, from a clinical perspective, it has an disadvantage because motion segments are decreased and place excessive axial compression load on adjacent motion segments. A meta-analysis for the effectiveness of fixation levels with pedicle screw fixation suggested that extension of fixation was not necessary to stabilize thoracolumbar fractures. In a prospective clinical study of fixation length in PIF for thoracolumbar unstable fractures, there was no difference in bone healing according to fixation length, and better clinical outcomes were reported in the short segment fixation group. Intermediate screws, or pedicle screw fixation at fractured vertebrae, can be used to improve the construct of stability and decrease the stress of pedicle screws in the upper and lower normal vertebrae. Moreover, intermediated screw fixation showed better reduction of the fractured vertebrae, less re-collapse after surgery, and a lower fixation failure rate.

Building a support for anterior column is beneficial, as it reduces the load on the posterior instrumentation system required to counter the flexion moments and can reduce the fixation length. Vertebral corpectomy and anterior fusion with bone grafting can obtain adequate support for the anterior vertebral column, but it requires a long operating time and hospitalization, donor site complaints, potential damage of the vertebral vascular structure, and increased morbidity and mortality. However, transpedicular VA can also provide stability to the anterior vertebral column and reduce pedicle screw bending movement, thereby preventing early implant failure and late loss of correction. PPF and VA eventually take the same transpedicular approach: thus, they can be performed simultaneously in one surgical process.

In vertebral augmentation, polymethylmethacrylate (PMMA) bone cement is most popular because it has good biocompatibility and can rapidly establish strong mechanical support and stable function quickly. Nevertheless, over the long-term, PMMA cement occupies a space between the trabecular bone of vertebral body and interferes with the regeneration of vertebral
Bone healing; osteoclasts appear, raising concerns that bone resorption would be eventually greater than bone formation, resulting in bone loss. Some injectable calcium ceramics of bd-BGs are known for their biodegradability and remodeling properties that allow the bone substitute to be reabsorbed and new bone to be replaced by the host. Recently, bd-BGs formed by a matrix of calcium sulfate and calcium phosphate (CaSO₄/CaPO₄) have been introduced. It is a compound engineered for better resorption and bone remodeling. Because of the simple resorption by dissolution of CaSO₄, it creates an open pore structure that allows infiltration and vascular growth, allowing new bone ingrowth on the remaining component of CaPO₄ that works as a scaffold for new bone formation. In addition, results from animal model studies have shown that a bone substitute formed by calcium sulfate and calcium phosphate can improve new bone formation and potentially accelerate bone healing in the environment where micro-motion is allowed. There is also the advantage of vertebral augmentation enhancing the stability of the intermediate screw. In a study on the biomechanics of pedicle screw augmentation, it was noted that calcium sulfate/phosphate cement of bd-BGs was as effective in enhancing pedicle screw fixation as PMMA cement. Given these considerations, it is expected that using intermediate screws on the fractured vertebra and performing vertebral augmentation with bd-BGs at the same time will improve the stability of the construct in pedicle screw fixation and will theoretically promote secondary bone healing of vertebrae.

When bd-BGs were used, radiopacity shading was found in x-ray due to barium sulfate. The loss of radiopacity shading means that bioceramics were resorbed, which is known to promote bone remodeling. In addition, according to previous study, it was reported that calcium sulfate was partially absorbed and replaced with new bone at 6 weeks after surgery, and completely absorbed and replaced with new bone at 12 weeks after surgery. So, it is thought that calcium sulfate is absorbed usually within 6-12 weeks, and it was similarly found in our study. Although early absorption in some cases, it causes ingrowth of new bone remodeling and strengthening the pull out strength of the pedicle screw, and through this, it is thought to give initial stability to the vertebral body.

The PPF technique allows access to the vertebra through soft tissue windows. Therefore, it leaves minimal foot prints, with indirect fracture reduction without contact with the fracture, while preserving paravertebral musculature and spinal blood supply. Furthermore, despite concerns that PPF is less capable of fracture reduction compared to PIF, new pedicle screw fixation systems for effective deformity correction have been developed. In our study, we used a pedicle screw system that corrects spinal deformities using a compression/distraction rack (Viper 3D MIS correction system, Depuy-Synthes Spine, MA, US). It is expected to help restore up to the given height of the fractured vertebra and is expected to provide the advantage of forming intervertebral cavities, as in vertebral balloon kyphoplasty.

There are several limitations to the present study. This was a retrospective study involving a small number of patients, without a control group and a short follow-up period. Therefore, large-volume comparative studies should be carried out in the future. Moreover, there was no assessment of vertebral bone union according to the postoperative period. Particularly, posterior or posterolateral fusion was not performed in this study, which is considered to be a risk factor for the loosening of the interface between vertebral bone and pedicle screws after vertebral bone healing. In our study, the posterior instrumentation was removed from the patients whose bone union was confirmed on the computed tomography at least nine months after surgery, and there were no reports of relapsed back pain and reduction loss of fixation segments after the removal of posterior instrumentation. This result was consistent with those of previous studies that suggest that the removal of the posterior instrumentation (PI) will restore the segmental motion of fractured segments and alleviate clinical and radiologic outcomes. However, further prospective research is needed on the timing of the vertebral bone healing and the ideal time for PI removal.

Conclusions

In the treatment of thoracolumbar fractures, PPF
performed simultaneously with VA using a bd-BGs is technically feasible. Furthermore, it is a less invasive alternative that is expected to provide biological support to the anterior column to maintain sufficient stiffness without going through a highly invasive procedure to enhance biological vertebral bone healing.

**Declarations**

This study was approved by the institutional review board. The authors have no personal, financial, or institutional interest in any of the drugs, materials, or devices described in this article.

**Competing Interests**

The authors declare that they have no competing interests.

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흉요추부 골절에서 경피적 척추경 나사못 고정술 및 생체 공학 분해성 뼈 대체물을 사용한 척추체강화술

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연구 개요: 후향적 분석
목적: 본 연구에서는 경피적 척추경 나사못 고정술 및 생체 공학 분해성 뼈 대체물(bioengineered degradable bone graft substitutes)을 사용한 척추체강화술의 기술적 측면을 평가하고자 하였다.
선행 연구문헌의 요약: 흉요추부 골절에서 경피적 척추경 나사못 고정술 및 생체 공학 분해성 뼈 대체물을 사용한 척추체강화술의 유용성에 대해서는 알려진 바가 없다.
대상 및 방법: 본 연구는 생체 공학 분해성 뼈 대체물을 사용하여 경피적 척추경 나사못 고정술 및 척추체강화술을 동시에 시행한 급성 흉요추부 골절로 진단된 17명의 환자를 대상으로 하였다. 골절된 척추 및 바로 위와 아래의 인접한 척추를 포함하여 단분절 경피적 척추경 나사못 고정술을 시행하였다. 후방 지지기구는 컴퓨터 단층촬영으로 골유합이 확인된 후에서 수술 후 최소 9개월 이후 제거하였다. 시상면 콥 각도(Sagittal Cobb’s angle) 및 시각아날로그척도(Visual analogue scale)를 사용하여 임상적 결과를 평가하였다.
결과: 환자의 평균 연령은 62.12±8.18세였다. 모든 환자는 수술 후 최소 12개월 동안 추적 관찰되었으며 평균 추적 기간은 14.8±3.32개월이었다. 주입된 생체 공학 분해성 뼈 대체물의 부피는 3.84±0.19 ml였다. 시각아날로그척도 점수는 수술 2주 후 유의하게 호전되었다(p<0.001). 시상면 콥 각도는 수술 전 평균 26.68±3.93에서 수술 후 2.86±4.90(p<0.001)로 재정렬 되었다. 2명의 환자에서 인접한 상부 추간판으로 생체 공학 분해성 뼈 대체물 누출이 관찰되었으며, 1명의 환자에서 최하부 척추 골절로 인한 후만 각 증가가 관찰되었다. 그러나 유의미한 고정 실패나 척추체 재붕괴는 없었다.
결론: 경피적 척추경 나사못 고정술 및 생체 공학 분해성 뼈 대체물을 사용한 척추체강화술은 흉요추부 손상에 대한 비교적 간단하고, 효과적이며, 보다 적게 침습적인 치료법으로 생각된다.
색인 단어: 흉요추부 골절, 경피적 척추경 나사못 고정술, 척추체강화술, 생체 공학 분해성 뼈 대체물, 칼슘 기반 생물 활성 세라믹
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