Original

Short segment pedicle screw fixation by using additional screws at the fracture level - for the fixation of thoracolumbar burst fractures -

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Short segment pedicle screw fixation (non-segmental SSPSF) is an excellent technique to preserve segmental motion for thoracolumbar burst fractures (TLBFs). However, unacceptable failures, such as vertebral collapse and progression of kyphosis, have been reported. Therefore, to evaluate the effectiveness of SSPSF with additional pedicle screws in the fractured vertebra (segmental SSPSF) in maintaining fracture reduction, a clinical course for patients was followed until after implant removal.

This study included 11 patients in a non-segmental group (Group A) and 24 patients in a segmental group (Group B). The mean age was 48.7 years and 46.9 years, and mean follow-up duration was 36 months and 29.4 months.

The anterior vertebral height compression ratio (AVHC) at the time of injury (pre-operatively) in Group A and Group B was 41.67 % and 38.38 % (P=0.62). The local kyphosis angle (KA) was 14.55° and 14.04° (P=0.88). The immediate postoperative AVHC was 15.25 % and 10.88 %, respectively (P=0.08); and the KA was 1.18° and 1.42° (P=0.91). Satisfactory initial reduction was achieved in both groups. At the time of bone union, the AVHC was significantly different, 30.69 % and 13.61 %, respectively (P<0.05), and the KA was significantly different, 16° and 4.46°, respectively (P<0.05). After implant removal, the AVHC correction loss was only 3.5 % and 2.27 %, and the KA loss was only 4.5° and 3.46°.

Satisfactory initial reduction and kyphosis correction were achieved with SSPSF. However, reduction and kyphosis correction were not adequately maintained by non-segmental SSPSF, but they were effectively maintained by segmental SSPSF with additional pedicle screws in the fractured vertebra. In addition, implant removal is recommended to regain segmental motion.

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Introduction

Thoracolumbar burst fractures (TLBFs) are frequently encountered fractures associated with spinal cord injury. Satisfactory outcomes with conservative management of stable TLBFs have been reported, but no standard treatment has been established[1)]. However, it is generally agreed that surgical treatment is required for unstable TLBFs for recovery from nerve injury and early rehabilitation. Currently, posterior surgery is usually performed because of a high level of evidence showing less invasiveness and lower complication rates compared to anterior surgery[2)]. Short segment pedicle screw fixation without fusion (SSPSF) has become preferred as a minimally invasive technique as reported by Dick et al.[3,4)] This minimally invasive technique with short-segment fixation is excellent in terms of preserving spinal motion. Unacceptable failure rates of 9 % to 54 %[5-7)] however, including progression of vertebral collapse

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or kyphosis, and early device failures, have been reported. These disadvantages are still being investigated even when SSPSF is combined with augmentation vertebroplasty of the fractured vertebra[5].

Meanwhile, some biomechanical studies have studied the increase in device rigidity with additional pedicle screw implantation in a fractured vertebra[8-10]. The essential objective of SSPSF is to restore segmental motion by implant removal after fracture healing. However, follow-up observations until implant removal has seldom been reported[11]. Therefore, the aim of the present study was to follow-up on patients until implant removal and compare outcomes between conventional SSPSF (non-segmental SSPSF) and SSPSF with additional pedicle screws in the fractured vertebra (segmental SSPSF) for treatment of unstable TLBFs.

Materials and methods

In this study, of the 48 patients with TLBFs, where SSPSF (non-segmental or segmental) was performed between 2007 and 2015, 35 patients were followed-up completely until the implant removal operation. These patients were divided into two groups: Group A with 11 patients who had non-segmental SSPSF, and Group B with 24 patients who had segmental SSPSF.

Group A included 8 males and 3 females with a mean age of 48.7 years (20-72 years). The mean post-operative follow-up was 36 months (14-103 months), and the mean time for implant removal was 21 months (7-102 months). The level of injury was T12 in 4, L1 in 5, and L2 in 2 patients.

Group B included 11 males and 13 females with a mean age of 46.9 years (14-81 years). The mean post-operative follow-up was 29.4 months (9-67 months), and the mean time to implant removal was 16.2 months (7-27 months). The level of injury was T12 in 6, L1 in 11, and L2 in 7 patients. The mean thoracolumbar AO spine injury score (TL AOSIS)[12] was 7.73 points (6-12 points) in Group A and 7.67 points (6-10 points) in Group B (Table 1).

Radiological evaluation

Thoracolumbar AP and lateral radiographs and computed tomography (CT) scans were performed in all patients immediately after transport to the emergency care center. Plain X-rays and CTs at the time of injury, and X-rays immediately post-operatively, at the time of bone union, and after implant removal were evaluated. The anterior vertebral

Table 1. Summary of demographic data by group

Characteristics		Group A (n=11)	Group B (n=24)
Male		8	11
Female		3	13
Age(y)		48.7 (20-72)	46.9 (14-81)
Fracture level	T12	4	6
	L1	5	11
	L2	2	7
TLAOSIS (Points)		7.73 (6-12)	7.67 (6-10)
	A 1. 2. 3. 4	0. 0. 0. 4	0. 0. 0. 14
	B 1. 2. 3	2. 4. 0	1. 8. 0
	C	1	1
	N 0. 1. 2. 3. 4. Nx	0. 5. 2. 2. 0. 2	0. 15. 2. 6. 0. 1
Follow-up duration (months)		36.0 (14-103)	29.4 (9-67)
Time until implant removal (months)		21.0 (7-102)	16.2 (7-27)

(TLAOSIS: Thoracolumbar AO Spine Injury Score)

height compression ratio (AVHC) was calculated by the measurement method of Haas et al. (Fig. 1a)[13]. The local kyphosis angle (KA) was calculated as the angle formed by the lower endplate of the fractured vertebra and the upper endplate of the cephalad vertebra (Fig. 1b).

Surgical technique

Posterior surgery was performed using a paraspinal approach from one level above to below the fractured vertebra. First, 4 pedicle screws were inserted into the vertebrae above and below the fractured vertebra, and reduction by a distraction force was performed under fluoroscopy. Posteriorly displaced fragments were easily reduced by indirect decompression using posterior longitudinal ligament (PLL) ligamentotaxis. Restoration of the collapsed fractured vertebra and kyphosis correction were achieved at the same time (Group A). In Group B, the rod on one side for temporary stabilization in Group A was removed, and a pedicle screw was inserted into the fractured vertebra. Final fixation with a distraction force was then performed. Using the same procedure on the contralateral side, another pedicle screw was inserted into the fractured vertebra for final fixation.

Statistical analysis

SPSS software was used for statistical analysis. The paired student's t-test was used to compare data. The level of significance was a P value less than 0.05.

This study was approved by the Saitama Medical University International Medical Center Institutional Review Board.

Results

The mean AVHC at the time of injury (pre-operatively) was 41.7 % in Group A and 38.4 % in Group B, with similar compression in both groups (P=0.62). The mean AVHC immediately post-operatively changed to 15.25 % in Group A and 10.88 % in Group B, with good improvement in both groups (P=0.08). At the time of bone union of the fractured vertebra, AVHC increased to 30.69% in Group A, but it was maintained at 13.61 % in Group B, with a significant difference between the two groups (P<0.05). At the final evaluation after implant removal, AVHC was 34.2 % in Group A and 15.88 % in Group B, also had a significant difference (P<0.05) (Table2).

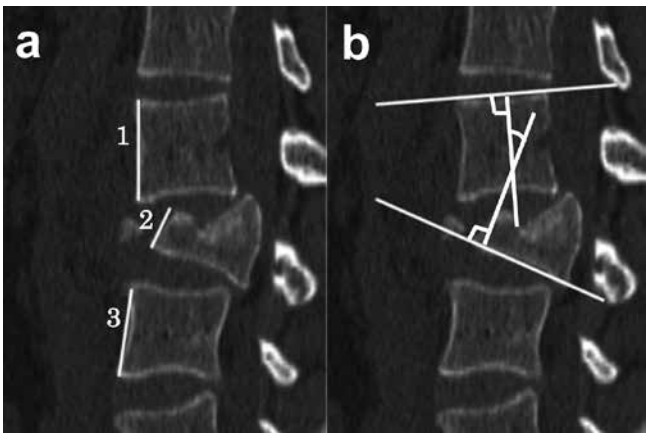


Fig. 1. Radiological evaluation: a) Anterior vertebral height compression ratio (AVHC) %: [1-(2× body height 2)/(body height 1+body height3)]×100)
b) Local kyphotic angle (KA).

Table 2. Anterior vertebral height compression ratio (AVHC)

	Group A	Group B	*P* value
Preoperative	41.67% ±14.55%	38.38% ±19.27%	0.62
Postoperative	15.25% ±7.01%	10.88% ±6.54%	0.081
Bone union	30.69% ±12.59%	13.61% ±6.63%	<0.05
After implant removal	34.2% ±12.33%	15.88% ±7.69%	<0.05

The mean KA at the time of injury (pre-operatively) was 14.55° in Group A and 14.04° in Group B; it was similar in both groups (P=0.88). Comparison of the mean KA immediately post-operatively showed good correction of the kyphosis in both groups; 1.18° in Group A and 1.42° in Group B (P=0.91). At the time of bone union, the mean KA increased to 16° in Group A, but kyphosis correction was maintained at 4.46° in Group B, with a significant difference between the two groups (P<0.05). At the final evaluation after implant removal, the mean KA was 20.55° in Group A and 7.92° in Group B. Kyphosis correction was significantly maintained in group B (P<0.05) (Table3).

Comparisons of the before and after implant removal groups showed an AVHC correction loss of 3.5 % (P<0.05) and KA loss of 4.5° (P<0.05) in Group A. The AVHC correction loss was 2.3%(P<0.05), and KA loss was 3.4° (P<0.05) in Group B (Tables 4, 5). However, there were no new changes involved with the biomechanical environment until implant removal.

Discussion

Surgery in short segment pedicle screw fixation for thoracolumbar burst fractures was performed not with a midline approach, but rather with a Wiltse's paraspinal approach. A minimally invasive surgery (MIS) system is reported to be effective in some studies[14], but because of the risk of guide pin perforation anterior to the vertebral body, it is generally not used for vertebral injuries. In this paraspinal approach, an incision is made under fluoroscopy between the pedicles above and below the fractured vertebra. The incision length is about 5 cm, about the same as with currently used MIS systems, so the degree of invasiveness to the paraspinal muscles is similar. This technique has many advantages, including direct visualization for safe screw insertion and fixation, and the ability to perform reduction using a distractor system.

The immediate post-operative AVHC results showed good initial restoration of vertebral body height with both non-segmental SSPSF and segmental SSPSF. This demonstrates the effectiveness of SSPSF using PLL ligamentotaxis. Reduction of a vertebral fracture is achieved with non-segmental SSPSF. Therefore, pedicle screw insertion into a fractured vertebra before vertebral body reduction should not be performed because it may impede reduction. Pedicle screw insertion after vertebral body reduction helps to

Table 3. Local kyphosis angle (KA)

	Group A		Group B		*P value*
Preoperative	14.55	±7.35°	14.04	±9.91°	0.88
Postoperative	1.18	±5.93°	1.42	±5.26°	0.91
Bone union	16.00	±11.38°	4.46	±6.71°	<0.05
After implant removal	20.55	±11.22°	7.92	±6.96°	<0.05

Table 4. Anterior vertebral height compression ratio (AVHC)

	Before implant removal	After implant removal	*P* value
Group A (n=11)	30.69% ±12.59%	34.2% ±12.33%	<0.05
Group B (n=24)	13.61% ±6.63%	15.88% ±7.69%	<0.05

Table 5. Local kyphosis angle (KA)

	Before implant removal	After implant removal	*P value*
Group A (n=11)	16.00 ±11.38°	20.55 ±11.22°	<0.05
Group B (n=24)	4.46 ±6.71°	7.92 ±6.96°	<0.05

maintain vertebral restoration.

No studies have reported the optimal timing of pedicle screw insertion into the fractured vertebra to date, but it is important for initial successful vertebral reduction. Ligamentotaxis across the fractured vertebra can restore vertebral height and reduce a posteriorly displaced fragment at the same time (Figs. 2, 3). Posterior element resection such as a conventional decompressive laminectomy for a posteriorly displaced fragment can lead to spinal instability and subsequent device failure[15]. SSPSF is an excellent technique to reduce a fractured vertebra without destruction of posterior element.

Some vertebral collapse and kyphosis during the time until bone union occurred in both groups, but these were significantly less with segmental SSPSF (Figs. 2, 3). Device loosening often occurs during follow-up after non-segmental SSPSF, thus resulting in unacceptable progression of vertebral collapse (Fig. 2). On the other hand, with segmental SSPSF, even with marked vertebral collapse associated with posterior element fracture at the time of injury, reduction could be maintained until bone union (Fig. 3). In segmental SSPSF with pedicle screw insertion into the fractured vertebra, sagittal construct rigidity was reinforced, a finding that supports the results of previous biomechanical studies.[8-10] Not only is device rigidity reinforced, but also pedicle screws in the fractured vertebra play an important role in maintaining reduction of the vertebral upper endplate. SSPSF together with augmentation vertebroplasty of the fractured vertebra using calcium sulfate has also been reported[16]. However, the present study findings shows that this is not necessary.

To investigate the validity of implant removal, the results before and after implant removal must be evaluated. A comparison of the data before and after implant removal alone showed significant differences in AVHC and KA in both groups (Tables 4, 5). However, the degree of progression was only slight, with increases in AVHC of 3.5 % with non-segmental SSPSF and 2.3 % with segmental SSPSF, and increases in KA of 4.5° with non-segmental SSPSF and 3.4° with segmental SSPSF.

Some papers insist that the implant should not be removed because of kyphosis progression after implant removal[17]. Since the present study did show a significant difference from before to after implant removal, this view cannot be completely disregarded. However, if we consider the results after implant removal at the time of final evaluation,

Fig. 2. Group A case: This 20-year-old male fell from a height. TLAOSIS 12 points, B2N3. (a, b) CT shows the L2 burst fracture with significant posterior displacement.(c) After the initial procedure of non-segmental SSPSF (d) pedicle screw displacement occurs and AVHC increases until bone union (e) after implant removal.

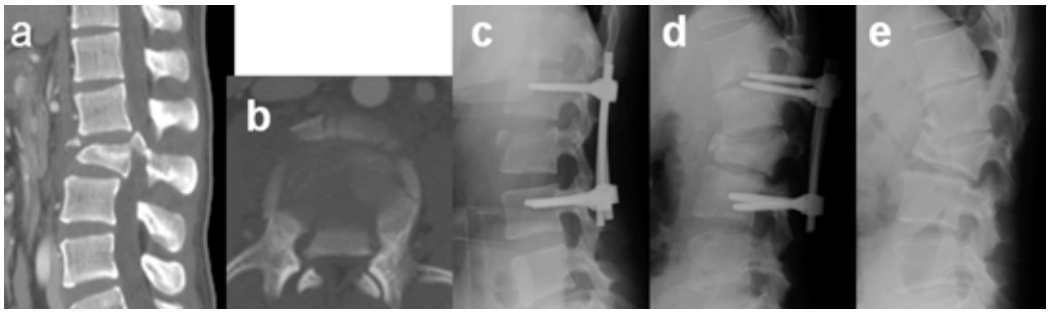
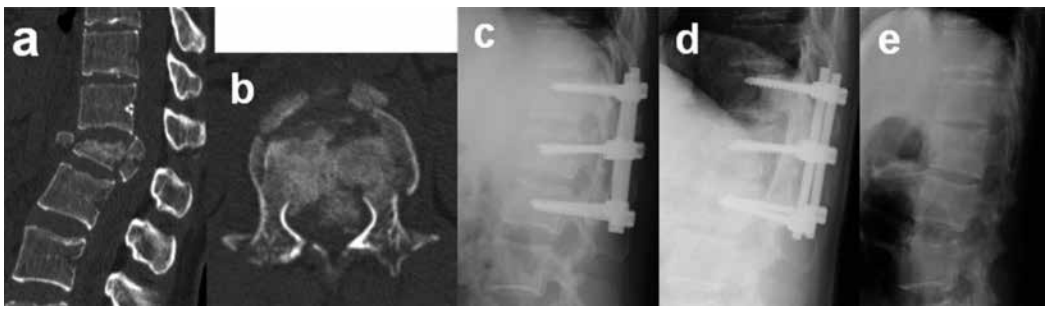


Fig. 3. Group B case: This 36-year-old female fell from a height. TLAOSIS 10 points. B2N3. (a, b) Note the kyphosis and significant posterior displacement visible on the sagittal CT with the splaying of the L1 pedicles on the axial CT. (c) Post initial procedure by segmental SSPSF (d) AVHC has not changed until bone union (e) after implant removal.



AVHC was 34.2 % and KA was 20.55° with non-segmental SSPSF, whereas AVHC was 15.88 % and KA was 7.92° with segmental SSPSF (Tables 2, 3; all $P<0.05$). Clinically significant kyphosis is usually ≥20°, yet with segmental SSPSF, the KA after implant removal remained ≤10°, well within physiological normal limits. Therefore, these statistical results alone should not be a reason to avoid implant removal.

Motion preservation after implant removal with SSPSF has been reported[11]. With an aging society increasing in number, variations in the sagittal construct, particularly at the thoracolumbar junction, can easily lead to future osteoporotic compression fractures of adjacent vertebrae due to stress concentration. Therefore, even with a short segment fixation, implant removal is recommended. However, further studies are needed in order to verify whether segmental SSPSF can be used for elderly patients with osteoporotic vertebra.

Conclusion

The present study shows that SSPSF with additional pedicle screws in a fractured vertebra in unstable TLBFs can effectively maintain reduction of the fractured vertebra. Moreover, with segmental SSPSF, the KA can be maintained within physiological normal limits even after implant removal. We believe that implant removal after bone union is beneficial.

Conflict of interest statement

The authors declare that there are no conflicts of interest associated with the present study.

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胸腰椎破裂骨折に対する損傷椎スクリューを追加した short segment pedicle screw fixation

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胸腰椎破裂骨折に対するshort segment pedicle screw fixation without fusion（non-segmental SSPSF）はmotion segmentを温存できる点で優れた方法である．一方で椎体圧潰や後弯変形の進行など許容できない悪化例の報告がある．骨折椎にpedicle screwを追加したSSPSF（segmental SSPSF）が整復位の維持に有効であるかを検討する為，implant抜去後までの経過を追跡調査した．non-segmental（group A）: segmental（group B）11 例: 24 例を対象とした．平均年齢は 48.7 歳: 46.9 歳，平均経過観察期間は 36 カ月: 29.4 カ月だった．

受傷時のanterior vertebral height compression ratio（AVHC）はgroup A 41.7 %: group B 38.4 %（P=0.62），local kyphosis angle（KA）は 14.55 度: 14.04 度（P=0.88）だった．術直後ではAVHCは 15.25 % : 10.88 %（P=0.08），KAは 1.18 度:1.42 度（P=0.91）と両群ともに良好な整復位が得られていた．骨癒合した時点では，AVHCは 30.69 %: 13.61 %（P<0.05），KAは 16 度: 4.46 度（P<0.05）と有意差があった．Implant抜去後では，AVHCの矯正損失は 3.5 %: 2.27 %，KAの損失角は 4.5 度: 3.46 度と僅かであった．胸腰椎破裂骨折の初期整復と後弯矯正はSSPSFで十分に得られる．しかしながら整復位と後弯矯正の維持はnon-segmental SSPSFでは不十分であり，骨折椎にpedicle screwを追加したsegmental SSPSFが有効であった．motion segmentの再獲得のためにはimplant抜去が推奨されると考えられた．

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