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Original Article

Effect of pedicle screw placement into the fractured vertebra in management of unstable thoracolumbar and lumbar fractures

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Abstract: Background: Pedicle screw insertion at the level of the fractured vertebra has been shown to improve clinical and radiological outcomes in unstable thoracolumbar and lumbar fractures, albeit this requires further evidence. The study aims to evaluate the effect of pedicle screw placement on the fractured vertebra in such cases. Methods: A prospective study included adult patients with thoracolumbar and lumbar fractures treated with short-segment posterior instrumentation with a pedicle screw into the fractured vertebra. Anterior vertebral body height loss, kyphotic angle and degree of spinal canal compromise were measured preoperatively and postoperatively in radiographs and CT scans. The neurological status was followed up for one year of the postoperative period. Results: The study included a total of 30 patients. Five patients (16.7%) had grade C, three patients (10%) had grade D, and 22 patients (73.3%) had grade E neurological status. The mean (SD) preoperative kyphotic angle, vertebral body height and canal compromise were 5.54 (5.35), 39.67% (8.04), and 31.59% (10.62), respectively. Postoperatively there was a significant canal decompression, with a mean postoperative spinal canal compromise of 5.53% (SD=7.70; *p*-value <0.001). At the end of one year of follow-up, the radiological evaluation showed a correction of the kyphotic angle to 6.62 (SD=2.57; *p*-value <0.001), and the mean anterior vertebral body height was 70.38% (SD=11.25; *p*-value <0.001). At the end of one year, there was a significant overall neurological recovery with a final neurological status of grade D in 5 (16.7%) and grade E in 25 patients (83.3%). There was no significant association between canal decompression and neurology at the end of the one-year follow-up. Conclusion: Unstable thoracolumbar and lumbar fractures surgically treated with short-segment fixation with an additional intermediate screw can achieve significant restoration of vertebral body height and correction of kyphotic angle without any added complications.

Keywords: Pedicle screw, thoracolumbar fracture, posterior instrumentation, intermediate screw, kyphotic angle, canal compromise

Introduction

The dorsolumbar junction of the human spine, which extends from the 11th Dorsal (D11) to 2nd Lumbar vertebrae (L2), is involved in 60-70% of all traumatic spinal fractures. The therapeutic aims for these fractures comprise restoring vertebral column stability and minimizing deformity, decompression of the neural canal, and prompt mobilization [1]. The surgical technique can be anterior, posterior, or in combination, with the posterior approach is the most chosen by surgeons.

Long-segment fixation provides secure fixation and superior canal healing but results in an immobile spine [2]. Short-segment fixation with pedicle screws placed one vertebra above, and one vertebra below the broken level has recently been the preferred operating procedure due to the ease of insertion, use of fewer fixation elements, reduction in blood loss, and compact incision [3-5]. However, the downsides of the fixation described above have been reported, including loss of correction over time, inaccurate instrumentation, and increased kyphotic angle [3, 6, 7].

Dick et al. conducted biomechanical research on pedicle screw instrumentation in a broken vertebra. Since then, the procedure has advanced and has shown that pedicle screw instrumentation in such vertebrae can attain sturdier implantation and decreased reduction loss in comparison with traditional four-screw fixation [8, 9]. But misposition of screws can lead to several problems in patients with various consequences, including new neurological symptoms (radicular pain, motor or sensory impairment) and vascular complications [8].

The intermediate screw, inserted at the broken vertebra's level, has enhanced clinical and radiological results. Although relevant studies regarding the intermediate screw fixation have been published, most of them have been from western countries, and there is a paucity of such studies in a developing nation like India. Hence this study has been performed at a tertiary center in India to see how pedicle screw implantation into the fractured vertebra affects the treatment of unstable thoracolumbar and lumbar fractures in an Indian population.

Materials and methods

Study design

From November 2016 to May 2018, the Department of Orthopaedic Surgery in a tertiary care hospital performed prospective longitudinal observational research.

Inclusion criteria

Patients aged 18 and above with unstable thoracolumbar and lumbar vertebra fractures (From 11^{th} Dorsal to 2^{nd} Lumbar vertebrae) were considered for inclusion. According to the AO classification, the fracture must be a single segment fracture with type A fracture; the time interval between the trauma and surgery is less than two weeks and a minimum follow-up period of 1 year.

Exclusion criteria

Our exclusion criteria included patients with incomplete data, dual or multiple segment fractures, follow-up of less than one year, old unstable thoracolumbar and lumbar vertebra fractures, spinal deformity, spinal tumour, and osteoporotic or pathological fracture.

Study group

Patients who met the inclusion criteria were contacted and informed about the research. The sampling technique of convenience was utilised. The patient was provided with the information leaflet in a language they understood. Following informed consent, baseline data were gathered by the proforma.

Neurological assessment

The patient was clinically assessed before the surgery to determine their neurological condition and other concomitant injuries. The radiographic assessment was performed after the patient had been stabilised. From arrival, the individuals' neurological health was checked every 2^{nd} hour on the first day. The bulbocavernosus response's reemergence was regarded as the culmination of spinal shock. The neurological impairment assessed following spinal shock's conclusion is considered the first neurological condition. The neurological condition was classified using the American Spinal Injury Association's modified Frankel's grading system for traumatic paraplegia [4]. Complete and incomplete spinal cord injuries were subdivided into five categories (A, B, C, D and E). Frankel grade A patients are those with complete motor and sensory lesions. Grade B patients have sensory-only functions below the level of injury. Grade C patients have some degree of motor and sensory function below the level of damage, but their retained/recovered motor function is useless. Grade D patients have useful but abnormal motor functions below the level of injury. Grade E patients have complete motor/sensory recovery before discharge from the hospital.

Radiographic assessment

Antero-posterior and lateral radiographs were acquired to evaluate the fractured vertebra, loss of anterior vertebral body height, and kyphotic angle. Cobb's technique was used to calculate the segmental kyphotic angle across the damaged vertebra on the lateral radiograph, which is the angle between two lines drawn perpendicular to the upper endplate of the uppermost vertebra involved and the lower endplate of the most inferior vertebra involved [**Figure 1**].

Similarly, the anterior height of the vertebral body was determined on the lateral radiograph, and the compression was calculated using the Mumford et al. method [**Figure 2**]. The formula

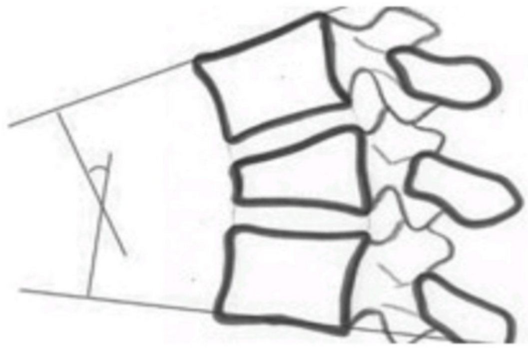

Figure 1. Measurement of kyphotic deformity by Cobb's method.

calculates the percentage of anterior body height compression (% ABC): % ABC=100 - 2a/(b + c) 100, where a is the height of the fractured vertebra; b is the height of the proximal vertebra, and c is the height of the distal vertebra.

Computerised tomogram (CT) scans were used to examine all the participants in the research. The width of the pedicle screws was calculated in all the patients, and the practicality of inserting the screws into the fractured vertebra was established. In the axial slices of the CT image, the smallest mid-sagittal diameter of the vertebral canal at the fractured vertebra was estimated (x). The mean of the mid-sagittal canal diameters of two adjacent vertebrae, one above and one below the affected level, was considered the likely mid-sagittal diameter of the fractured vertebra before injury (y). The amount of spinal canal compromise (a) preoperatively was determined using the method described by Hashimoto et al. [10] [**Figure 3**].

$$a=(1 - x/y) * 100$$

MRIs were performed on all individuals to assess the posterior ligament complex and the mechanism of injury, and the TLICS (Thoraco-Lumbar Injury Classification and Severity score) was utilised to classify fractures, which uses the integrity of posterior ligamentous complex, the morphology of fracture and neurological impairment to determine the need for surgery.

Surgical procedure

Before the surgery, the feasibility of pedicle screw placement was analysed, pedicle breadth, diameter, and screw route length were measured, and a pedicle screw of 30-40 mm size was chosen. The patients were operated on under general anaesthesia in a prone position. An image intensifier was used to check the fracture level before the incision. The posterior midline incision was centred on the fractured vertebra and extended one level above and below the fractured vertebra to expose the vertebral plate and the articular process layers. Magerl's surgical approach was utilised to determine the entry sites and orientation of pedicle screws in the vertebrae [11]. Probes were then inserted into each pedicle channel of the fractured and adjacent vertebrae. This was followed by proper pedicle screw insertion 1 or 2 levels above and below the fractured vertebra. The pedicle screw was placed during the procedure using a free-hand approach. The kyphotic deformity could be partially corrected through the prone hyperextension position, and a unilateral prebent rod was provisionally placed to help recover the height of the collapsed vertebra. Indirect decompression was achieved at the site of the damaged vertebra by distraction and ligamentotaxis, followed by postero-lateral fusion. The wound was washed and closed in layers over a drain. A single surgeon performed all operations.

Postoperative protocol

Following surgery, the patients were typically given prophylactic antibiotics according to protocol, motivated to begin out-of-bed movements with orthotics within seven days, and rehabilitated based on their neurological state. Any other issues were dealt with as they arose. Excessive and strenuous activities, on the other hand, were prohibited for half a year. The early postoperative neurological state was recorded and reviewed at 3-month intervals for up to a year.

Anteroposterior and lateral radiographs were taken after surgery to assess the restoration of spinal height and improvement in kyphotic angle, and the percentage of correction was calculated. CT images were used to calculate the proportion of post-surgical spinal canal compromise using the previously established method. The below equation was utilised to calculate the degree of indirect decompression:

$$[(a - b)/a] * 100$$

Where 'a' represents the spinal canal compromise before surgery, and 'b' represents the spinal canal compromise after surgery.

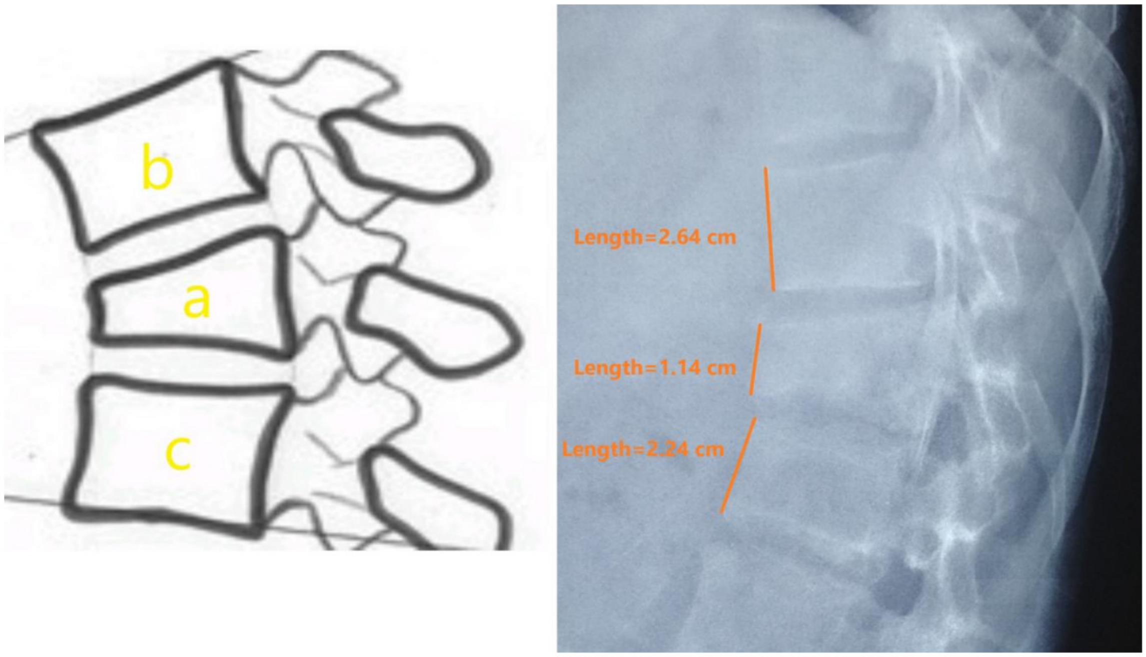

Figure 2. Percentage of anterior body height compression (% ABC): Percentage of anterior body height compression (% ABC) is calculated by the formula: % ABC=100 - 2a/(b + c) 100, where a is the height of fractured vertebra; b is the height of the proximal vertebra; and c is the height of the distal vertebra (A). B is an example measured by the PACS measurement software.

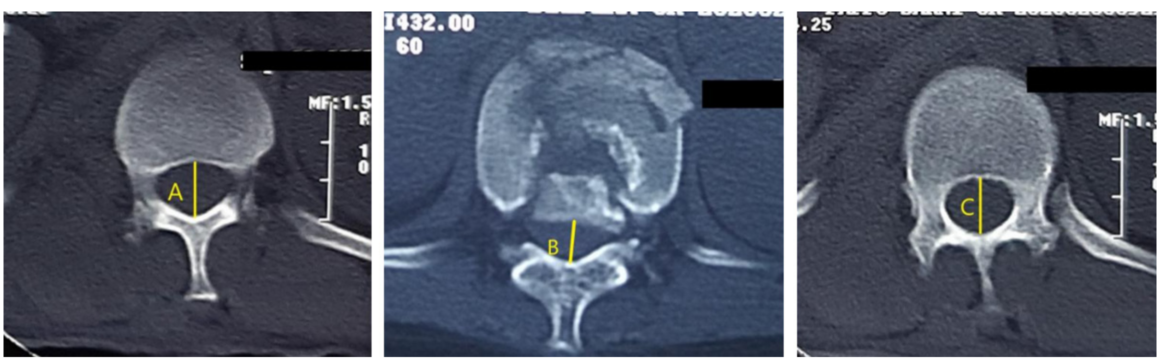

Figure 3. Measurement of mid sagittal diameter: A and C indicate the midsagittal diameter of normal vertebra above and below. B indicates mid-sagittal diameter at the fractured level. The mean canal diameter of normal vertebra was considered normal mid-sagittal diameter of fractured vertebra.

The precision of the pedicle screw position was estimated using the postsurgical axial 3-mm slice computed tomography scans with the help of the grading score described by the Gertzbein scale. As per the Gertzbein scale, grade 0 indicates no cortical breach; grade 1 suggests up to 2 mm minor cortical violation, grade 2 means 2 to 4 mm cortical breach and grade 3 shows more than 4 mm cortical breach. "Safe zone or acceptable" zone included pedicle screws under grade 0 and 1 and likewise the "unsafe zone" included the screws were under grade 2 and 3 [12, 13].

Statistical analysis

The Statistical Package for Social Sciences (SPSS) for Microsoft Windows version [17] was used for statistical analysis. Numbers and percentages were used to summarise categorical measures, and the average and standard deviation were used to summarise numerical measurements. The paired t-test was used to determine the reliability of canal diameter and pedicle screw position measurements amongst and between observers. The paired t-test was also used to determine the degree of indirect

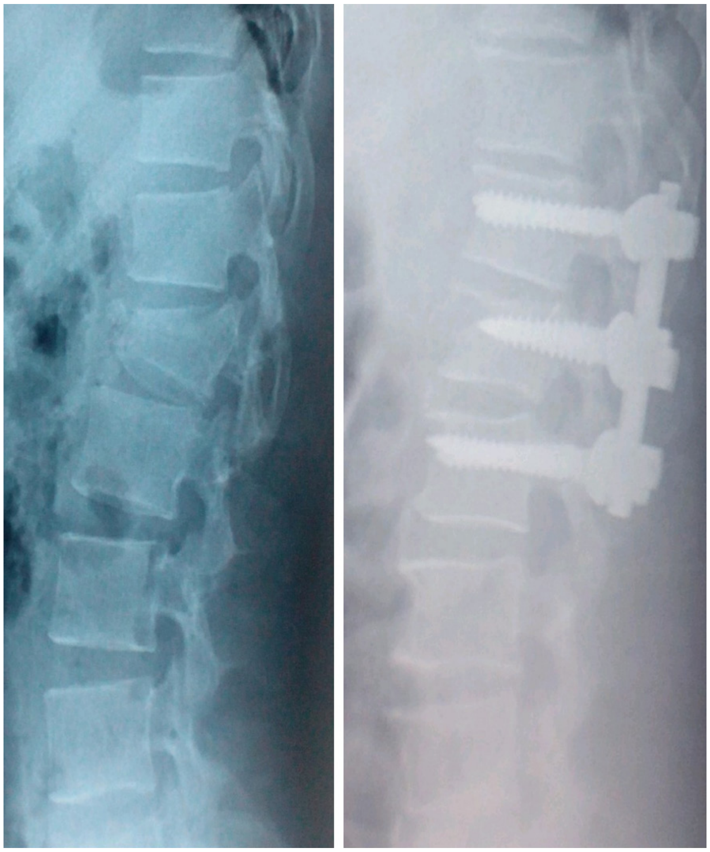

Figure 4. Lateral radiographs of thoracolumbar spine showing fracture at the level of L1. Left picture depicts pre-operative radiograph which shows loss of anterior vertebral body height and the right picture depicts postoperative radiograph which shows restoration of anterior vertebral body height following pedicle screw instrumentation.

decompression, postoperative vertebral height restoration, and kyphotic angle resolution. A *p*-value of less than 0.05 was deemed statistically significant.

Results

Demographics

A total of 32 patients who met the inclusion criteria were initially considered for inclusion. However, two were later lost to follow-up; hence, 30 patients were enrolled and evaluated for final review. Eighteen individuals were hospitalised 24 hours after the injury, while the remaining 12 were evaluated 24 and 48 hours later. The mean age of the patients was 41.4 years, with 23.3% below 30 years, 26.7% between 31 to 50 years, and 50% above 50 years of age. There were 27 men (nine-tenth of the total) and three females (one-tenth of the total). The ratio of men to women was 9:1, highlighting the predominance of males involved with dorsolumbar fractures in India. The most prevalent method of injury was a fall from a great height (three-fifth of total), followed by road traffic accidents (RTA) (two-fifth of total). Twenty-five individuals had dorsolumbar (11^{th} Dorsal to 1^{st} Lumbar) fractures and five with lumbar (2^{nd} to 3^{rd} Lumbar) fractures. The L1 vertebra was the most frequently affected (17 subjects). Four patients had related lower limb fractures, which were treated appropriately. On comparison between males and females, and based on the age group, no significant correlation was found between neurological recovery and age or sex.

Neurological assessment

Neurology was examined and rated following the end of spinal shock using the American Spinal Injury Association's modified Frankel's grading of traumatic paraplegia. Five subjects received a C, three subjects received a D, and 22 subjects received an E.

Radiological assessment

All patients undergoing surgery had a preoperative radiological assessment. Cobb's approach yielded an average (SD) pre-operative kyphotic angle of 15.5 degrees (5.4). The average (standard deviation) preoperative vertebral body length was 39.7% (8). Preoperative canal occlusion was 31.6% on average (SD) (10.62). The immediate postoperative radiographic assessment revealed that the kyphotic angle had been corrected to eight degrees (SD=2.6) and that the vertebral body height had been restored, with the average postoperative anterior vertebral body height being 69.5% (SD=13.9). There was considerable canal decompression post-operatively, with an average postoperative spinal canal compromise of 15.5% (SD=7.7; *p*-value <0.05). After one year of follow-up, the radiographic investigations showed that the kyphotic angle had been corrected to 6.6 degrees (SD=2.6; *p*-value <0.05), and the average anterior vertebral body height was 70.4% (SD=11.3; *p*-value <0.05) [**Figures 4** and **5**; **Table 1**].

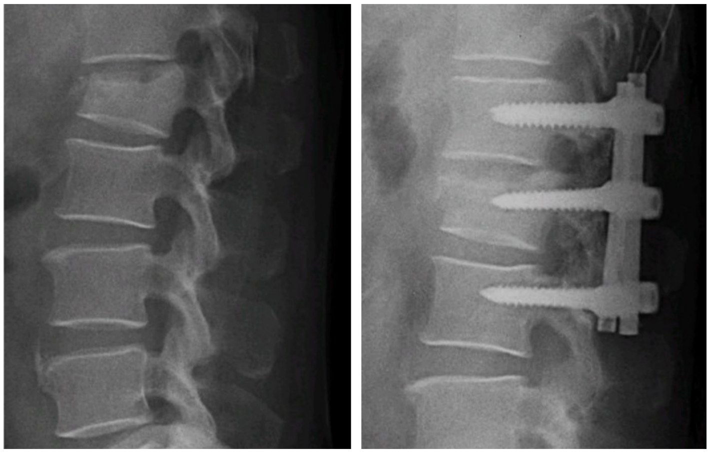

Figure 5. Radiograph of L1 bust fracture pre-operative and postoperative with placement of intermediate screw into the fractured vertebra (restoration of vertebral body height and reduced kyphotic angle).

Pedicle screw location

Using the free-hand approach, 180 pedicle screws were inserted into the vertebra via the pedicle. Sixty pedicle screws were put at the broken vertebra level, and the remaining 120 were implanted in the neighbouring vertebra, one superior and one inferior to the fractured vertebra. 10 (5.6%) pedicle screws were located in a dangerous zone, whereas the remaining 170 (94.4%) pedicle screws were situated in a safe zone. The deviation of pedicle screws was classified into four grades, with grade 1 accounting for the vast majority (Grade 0= 26.66%, grade 1=67.66%, grade 2=3.27%, and grade 3=2.27%). Three pedicle screws showed medial deflection, while seven showed lateral deflection. Three pedicle screws deviated at the level of the fractured vertebra, and seven pedicle screws deviated superior to the fractured vertebra. Neurology did not deteriorate significantly in individuals with pedicle screw deviation, with neurology being consistent [**Figure 6**].

Follow-up

After a duration of a year, there was a remarkable aggregate neurological improvement, with five (16.66%) subjects receiving a final grade of D and 25 (83.27%) receiving a final grade of E [**Table 2**]. After the last follow-up (one year), there was no significant relationship between canal decompression and neurology [**Table 3**]. There were no complications after surgery, such as surgical site infection. The follow-up review revealed no vascular or visceral complications, as well as no neurological impairment.

Discussion

Surgical indications for pedicle screw fixation include more than 50% loss of anterior vertebral body height, regional kyphotic deformity of more than 20 degrees or significantly involved posterior elements. In patients with B2 injury with A3/A4 fractures of the vertebral body at the thoracic level, posterior long segment fixation is performed to provide better reduction forces. This can benefit rotationally unstable injuries with high stress on the posterior implants. Contraindications to pedicle screw fixation are few and include congenital anomaly of the cervical pedicles, pedicle erosion by significant Dural ectasia in patients with neurofibromatosis or Marfan syndrome or Metal allergy.

The best way to treat dorsolumbar fractures is still up for debate. Because of its minimal morbidity, posterior transpedicular fixation is the most often performed operation for these injuries [14]. Pedicle screws are exclusively placed at levels immediately next to the broken vertebra in conventional bisegmental fixation (superior and inferior to the level of fractured vertebra). According to studies, bisegmental pedicle screw fixation was insufficient to accomplish and sustain reduction and was linked with a significant failure rate [15]. The persistent kyphotic deformity increases the tension on pedicle screws, resulting in screw failure, displacement, and separation owing to stress. When there is neurological impairment, simultaneous anterior and posterior fixation is a therapeutic option that accomplishes total kyphosis rectification, immediate stabilisation, and comprehensive spinal canal decompression [16]. Expanding the instrumentation levels reduces the tension on individual pedicle screws; however, it decreases the protective benefit of movable segments over bisegmental fixation.

The latest option that has become more popular is inserting a screw into the broken vertebra [9]. In cadaver research done by Mahar et al., placing pedicle screws at the injury site and

Table 1. Summary of Radiographic Measurements

Measurement	Preoperative mean value (Standard Deviation)	Immediate Postoperative mean value (Standard Deviation)	1-year Postoperative Mean value (Standard Deviation)	Significance between initial and final value
Kyphotic angle (Cobbs angle)	15.54 degrees (5.35)	8 degrees (SD=2.60)	6.62 degrees (SD=2.57)	P<0.001
Vertebral body height	39.67% (8.04)	69.53% (SD=13.91)	70.38% (11.25)	P<0.001
Canal compromise	31.59% (10.62)	15.53% (SD=7.70)	NA	P<0.001

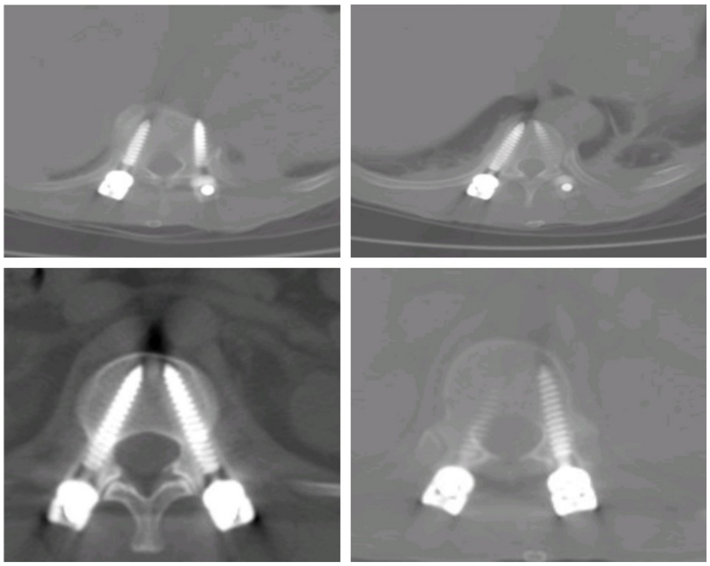

Figure 6. Postoperative CT scan pictures of the vertebra showing pedicle screw and shows deviation of pedicle screw from the normal. Bottom right picture depicts medial deviation of the pedicle screw. And the rest three shows lateral deviation of pedicle screw.

Table 2. Significant neurological recover at the end of one year follow-up following pedicle screw fixation (Wilcoxon signed rank test P=.011)

		NEUROLOGY 12MTH-D	NEUROLOGY 12MTH-E	TOTAL
NEUROLOGY PRE	C	4	1	5
		80%	20%	100%
		80%	4%	16.7%
	D	1	2	3
		33.3%	66.7%	100%
		20%	8%	10%
	E	0	22	22
		0%	100%	100%
		0%	88%	73.3%
TOTAL		5	25	30
		16.7%	83.3%	100%
		100%	100%	100%

bisegmental pedicle screw instrumentation was demonstrated to dramatically enhance vertebral stability in burst fractures [8]. Cavities emerge inside the fractured vertebra following height reestablishment in bisegmental fixation performed without inserting a pedicle screw at the fractured level, potentially resulting in the correction failure. All the patients in this research were operated using a posterior route with transpedicular screw fixation, including the broken vertebra.

Shuman et al. discovered no correlation between neurological recovery and betterment in postoperative canal compromise; Herndon reported an identical conclusion, which is validated in the current investigation. Following posterior fixation, there was considerable spinal canal decompression. In our research, placing a pedicle screw at the level of the injured vertebra resulted in substantial correction of vertebral body height and rectifying the kyphotic angle.

The precision of screw insertion is vital for efficient operation. A CT imaging is performed before surgery to determine the practicality of inserting a pedicle screw into a broken vertebra. When using a free-hand approach, screw placement precision was evaluated using the 2 mm grading system with the "in" or "out" categorisation method. According to Yahiro's research, 146 (2.5%) of patients operated with pedicle screws had malpositioned screws, and 99 (1.7%) suffered neurological impairment [17]. In 617 patients, 13 surgeons in the USA discovered a preponderance (2.3%) of persistent nerve root damage owing to pedicle

Table 3. Association between mid-sagittal diameter and neurology (pre & postoperative)

	PRE-OP	N	MEAN	S.DEV	MEDIAN	IQR	*P* Value
% CC PRE-OP	C	5	38.4	5.2	36	(34-44)	0.004
	D	3	43.7	8.9	39	(38-54)	
	E	22	28.4	10	32.5	(21-33.3)	
% CC POST-OP	C	5	15	3.3	14.2	(12.5-18)	0.451
	D	3	18.5	7.7	18	(11-26.4)	
	E	22	15.2	8.5	12	(10.7-16.3)	

	PRE-OP	POST-OP	*P* Value
% CC PRE-OP	C	D	1.000
		E	0.121
	D	C	1.000
		E	0.040
	E	C	0.121
		D	0.040

No overall significant association between pre-operative canal compromise and neurology at the end of one year follow-up.

screw instrumentation [18]. In this research, there was a greater risk of pedicle screw malposition (5.6%), with the malposition rate being roughly 1.57% at the fractured level and 3.87% at the adjacent vertebra, although no individuals had any neurological or vascular complications.

Review studies comparing long-segment and bisegmental instrumentation revealed that radiological indices for anterior vertebral body height decrease, kyphotic angle, and sagittal index were superior in multisegment instrumentation than in bisegmental instrumentation [19]. However, there was no substantial variation in patient outcomes between multisegment and bisegmental instrumentation. The bisegmental posterior instrumentation, on the other hand, has several drawbacks, including screw loosening, inadequate neurological decompression, and poor correction [15, 18, 20]. Inserting an intermediate screw into the broken vertebra reduces the degree of kyphotic corrective loss [8, 9, 21, 22]. The cadaveric study by Mahar et al. demonstrated higher biomechanical stability, and the results have also translated to a few clinical studies [8]. Guven et al. have shown lower rates of correction failure in short segment constructs, suggesting that such fixation can achieve and maintain kyphosis correction [21]. Farrokhi et al. have also shown a comparable clinical and functional outcome with few failures and no additional complications with such fixation and stated that the inclusion of fractured vertebra could offer better kyphosis correction [22].

Our study has demonstrated significant improvement in the kyphosis angle, vertebral height, and canal compromise without further complications. However, canal decompression was not associated with the final neurological recovery at a one-year follow-up. The authors' last view is that intermediate screw fixation can be adequate in single-level thoracolumbar fractures to reduce the loss of correction, provided optimal preoperative assessment is done to determine the feasibility of pedicle screw fixation and experienced surgeons with expertise perform it to avoid screw malposition.

The present study has a few limitations. First, the sample size is small, and the study has no control group. Secondly, the study's follow-up period was limited to one year of the postoperative period. The subsequent studies in the future can be comparative trials with longer follow-up and larger patient groups to arrive at more robust evidence regarding the outcome.

Conclusion

Unstable dorsolumbar and lumbar fractures treated operatively with bisegmental instrumentation with an extra screw in the fractured vertebra can result in considerable restoration of vertebral body height and restoration of kyphotic angle without any further complications. Substantial spinal canal decompression has also been reported after posterior instrumentation with a pedicle screw at the fractured vertebra, although this does not correspond to neurological improvement. In individuals with pedicle screw deflection, there was no substantial impairment in neurology. Pre-operative CT imaging for patients with unstable dorsolumbar and lumbar fractures is valuable for determining pedicle screw size and screw route distance for pedicle screw insertion.

Disclosure of conflict of interest

None.

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References

[1] Denis F. The three column spine and its significance in the classification of acute thoracolumbar spinal injuries. Spine (Phila Pa 1976) 1983; 8: 817-831.

[2] Müller U, Berlemann U, Sledge J and Schwarzenbach O. Treatment of thoracolumbar burst fractures without neurologic deficit by indirect reduction and posterior instrumentation: bisegmental stabilization with monosegmental fusion. Eur Spine J 1999; 8: 284-289.

[3] Altay M, Ozkurt B, Aktekin CN, Ozturk AM, Dogan O and Tabak AY. Treatment of unstable thoracolumbar junction burst fractures with short- or long-segment posterior fixation in magerl type a fractures. Eur Spine J 2007; 16: 1145-1155.

[4] Maynard FM Jr, Bracken MB, Creasey G, Ditunno JF Jr, Donovan WH, Ducker TB, Garber SL, Marino RJ, Stover SL, Tator CH, Waters RL, Wilberger JE and Young W. International standards for neurological and functional classification of spinal cord injury. American Spinal Injury Association. Spinal Cord 1997; 35: 266-274.

[5] Gelb D, Ludwig S, Karp JE, Chung EH, Werner C, Kim T and Poelstra K. Successful treatment of thoracolumbar fractures with short-segment pedicle instrumentation. J Spinal Disord Tech 2010; 23: 293-301.

[6] Alanay A, Acaroglu E, Yazici M, Oznur A and Surat A. Short-segment pedicle instrumentation of thoracolumbar burst fractures: does transpedicular intracorporeal grafting prevent early failure? Spine (Phila Pa 1976) 2001; 26: 213-217.

[7] Gurwitz GS, Dawson JM, McNamara MJ, Federspiel CF and Spengler DM. Biomechanical analysis of three surgical approaches for lumbar burst fractures using short-segment instrumentation. Spine (Phila Pa 1976) 1993; 18: 977-982.

[8] Mahar A, Kim C, Wedemeyer M, Mitsunaga L, Odell T, Johnson B and Garfin S. Short-segment fixation of lumbar burst fractures using pedicle fixation at the level of the fracture. Spine (Phila Pa 1976) 2007; 32: 1503-1507.

[9] Dick JC, Jones MP, Zdeblick TA, Kunz DN and Horton WC. A biomechanical comparison evaluating the use of intermediate screws and cross-linkage in lumbar pedicle fixation. J Spinal Disord 1994; 7: 402-407.

[10] Hashimoto T, Kaneda K and Abumi K. Relationship between traumatic spinal canal stenosis and neurologic deficits in thoracolumbar burst fractures. Spine (Phila Pa 1976) 1988; 13: 1268-1272.

[11] Magerl FP. Stabilization of the lower thoracic and lumbar spine with external skeletal fixation. Clin Orthop 1984; 125-141.

[12] Abe Y, Ito M, Abumi K, Kotani Y, Sudo H and Minami A. A novel cost-effective computer-assisted imaging technology for accurate placement of thoracic pedicle screws. J Neurosurg Spine 2011; 15: 479-485.

[13] Wu ZX, Huang LY, Sang HX, Ma ZS, Wan SY, Cui G and Lei W. Accuracy and safety assessment of pedicle screw placement using the rapid prototyping technique in severe congenital scoliosis. J Spinal Disord Tech 2011; 24: 444-450.

[14] Dai LY, Jiang SD, Wang XY and Jiang LS. A review of the management of thoracolumbar burst fractures. Surg Neurol 2007; 67: 221-231; discussion 231.

[15] McLain RF, Sparling E and Benson DR. Early failure of short-segment pedicle instrumentation for thoracolumbar fractures. A preliminary report. J Bone Joint Surg Am 1993; 75: 162-167.

[16] Payer M. Unstable burst fractures of the thoraco-lumbar junction: treatment by posterior bisegmental correction/fixation and staged anterior corpectomy and titanium cage implantation. Acta Neurochir (Wien) 2006; 148: 299-306.

[17] Yahiro MA. Review of the "historical cohort study of pedicle screw fixation in thoracic, lumbar, and sacral spinal fusions" report. Spine (Phila Pa 1976) 1994; 19 Suppl: 2297S-2299S.

[18] Esses SI, Sachs BL and Dreyzin V. Complications associated with the technique of pedicle screw fixation. A selected survey of ABS members. Spine (Phila Pa 1976) 1993; 18: 2231-2238.

[19] Tezeren G and Kuru I. Posterior fixation of thoracolumbar burst fracture: short-segment pedicle fixation versus long-segment instrumentation. J Spinal Disord Tech 2005; 18: 485-488.

[20] Lonstein JE, Denis F, Perra JH, Pinto MR, Smith MD and Winter RB. Complications associated with pedicle screws. J Bone Joint Surg Am 1999; 81: 1519-1528.

[21] Guven O, Kocaoglu B, Bezer M, Aydin N and Nalbantoglu U. The use of screw at the fracture level in the treatment of thoracolumbar burst fractures. J Spinal Disord Tech 2009; 22: 417-421.

[22] Farrokhi MR, Razmkon A, Maghami Z and Nikoo Z. Inclusion of the fracture level in short segment fixation of thoracolumbar fractures. Eur Spine J 2010; 19: 1651-1656.