Retrospective Analysis of Three Posterior Open Surgical Approaches for the Intraoperative and Long-term Outcomes in the Treatment of Thoracolumbar Burst Fractures

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Abstract

Objective Evaluating the Intraoperative and Long-term Clinical Outcomes of Three Posterior Open Surgical Approaches for the Treatment of Thoracolumbar Burst Fractures.

Methods Follow-up observation of 145 patients with thoracolumbar burst fractures treated with three surgical approaches, including "traditional transpedicular four-screw fixation spanning the injured vertebral body (TFSV) (n=38), short-segment transpedicular four-screw fixation through the injured vertebral body (SFTV) (n=53), and six-screw fixation (STV) (n=54)", at our institution from June 2014 to June 2022. Comparative analysis of perioperative parameters (operative time, intraoperative blood loss, postoperative 24-hour drainage), preoperative and postoperative radiological indices (sagittal plane Cobb angle, Vertebral wedge deformity index), postoperative functional recovery (VAS score, ODI score), and incidence of complications.

Results There was no significant difference in general data among the three groups. The SFTV group is superior to the other two groups in perioperative parameters (P 0.001, P=0.023, P 0.001). There was significant difference in sagittal plane Cobb angle at each time point among the three groups (P=0.025), but no significant difference in Vertebral wedge deformity index (P=0.299). The improvement of sagittal plane Cobb angle was slightly worse in the group of SFTV. The VAS and ODI scores before and after surgery in each group showed significant improvement (P 0.001, P 0.001); however, there were no statistically significant differences between the groups at the same time points (P=0.312, P=0.924). The incisions of all the patients healed at the first stage without any complications. At the end of follow-up, the Cobb angle increased more than 10 degrees in 3 cases (16.67%) in the TFSV group and in 1 case (5.56%) in the SFTV group.

Conclusion The treatment of thoracolumbar burst fracture with STV or SFTV is superior to the TFSV, SFTV is better than STV, but the indication of SFTV is limited.

Introduction

The thoracolumbar vertebrae serve as stress concentration regions, and in instances of high-energy trauma to the body, there is a higher probability of vertebral fractures occurring in this segment[1–3]. Thoracolumbar burst fractures are commonly encountered in clinical practice[4]. Because such fractures primarily involve the anterior and middle columns, thereby affecting spinal stability, conservative treatments have limited effectiveness[5], and surgical intervention is often required. However, the specific surgical approach remains a topic of debate[6–8].

In recent years, with the development of percutaneous vertebroplasty (PVP), percutaneous kyphoplasty (PKP), and percutaneous pedicle screw fixation, there have been more treatment options available for thoracolumbar burst fractures[9–11]. However, for patients with spinal cord compression and TLICS score ≥ 4 points, traditional open surgery, which can effectively restore vertebral height, spinal physiological curvature, and perform laminectomy for decompression in parallel[12], remains the optimal choice for such cases[2, 13, 14].

This study retrospectively analyzed data from 145 patients with thoracolumbar burst fractures who underwent three different surgical procedures at our department between June 2012 and June 2022: traditional transpedicular four-screw fixation spanning the injured vertebral body (TFSV), short-segment transpedicular four-screw fixation through the injured vertebral body (SFTV) and six-screw fixation (STV). The analysis and evaluation included perioperative indicators, radiological parameters, functional assessment measures, and postoperative complications, with the aim of providing clinical insights for treatment selection.

Patient and methods

Patient enrollment

Inclusion criteria: (1) Single-segment thoracolumbar vertebral fractures without associated injuries; (2) Fractures occurring between T11-L4; (3) Classified as burst fractures according to the Denis classification [15]; (4) Within one week after injury; (5) TLICS score ≥ 4 points; (6) Preoperative CT examination indicating spinal cord compression. Exclusion criteria: (1) Old fractures; (2) Multi-segment fractures; (3) Pathological fractures; (4) Blood disorders such as coagulation abnormalities; (5) Not meeting surgical indications; (6) Other situations not suitable for surgery.

This study included a total of 145 patients with thoracolumbar burst fractures, comprising 64 male patients and 81 female patients, with ages ranging from 19 to 71 years and an average age of 43 years. Causes of injury: 63 cases from car accidents, 50 cases from falls from a height, and 32 cases from blunt trauma. Injured segments: 29 cases of T11, 35 cases of T12, 42 cases of L1, 20 cases of L2, 10 cases of L3, and 9 cases of L4. All were classified as burst fractures according to the Denis classification. Surgical approach: TFSV (n = 38), SFTV (n = 53) and STV (n = 54). The time from injury to surgery ranged from 8 hours to 5 days, with an average of 54 hours. All patients received follow-up examinations at 4 weeks post-surgery, with 56 patients having data available at the final follow-up stage. Among them, there were 18 cases in the TFSV group, 18 cases in the SFTV group, and 20 cases in the STV group, with the final follow-up durations ranging from 12 to 36 months postoperatively.

Surgical technique

The patients were placed under general anesthesia and positioned in the prone position. A spinal external fixation frame was placed on the operating table. A midline incision, centered around the spinous process of the injured vertebra, was made. Conventional techniques were employed to expose the vertebral body, vertebral arch, transverse processes, and facet joints of the injured vertebra and the adjacent vertebrae above and below it. C-arm fluoroscopy was used for guidance and to assess the reduction of the fracture. TFSV: Pedicle screws were inserted into the vertebrae above and below the injured vertebral body. SFTV: Pedicle screws were inserted into the injured vertebral body and an adjacent vertebra. STV: Pedicle screws were employed to achieve fixation in the injured vertebral body as well as the adjacent upper and lower vertebral bodies. Placing the pre-bent connecting rod, longitudinally expanding it, restoring vertebral height, realigning the fracture, securing it firmly, and confirming satisfactory fracture reduction through fluoroscopy with the C-arm, achieving excellent correction of kyphosis. If there is compression or rupture of the upper endplate of the fractured vertebral body, fixation is applied to the lower adjacent vertebra, while the upper adjacent vertebra is expanded. The same procedure is applied to the compression or rupture of lower endplate. Subsequently, fixation is performed on the distal end of the injured vertebral pedicle, followed by tightening the nut. For cases of flexion-distraction injuries, compression reduction is employed during fracture reduction. In addition to tightening the nut, a lateral connection is installed. In cases of preoperative absence of neurological symptoms, decompression of the vertebral plates is performed when the compressed area at the T11/12 level exceeds 35% of the spinal canal area and when the compressed area at the L1/2 level exceeds 45% and 55%, respectively. In cases of preoperative neurological symptoms, a posterior approach with complete vertebral plate excision is utilized for thorough decompression, including evaluation of the repositioning of the vertebral body's posterior wall. Vertebral plate posterior lateral bone graft fusion is performed, and a gelatin sponge is placed over the exposed dura mater, followed by meticulous layer-by-layer suturing. Plasma drainage tubes are removed 24–48 hours postoperatively. Patients wear lumbar braces for 2–3 weeks after the surgery to facilitate getting out of bed and moving. Following discharge, they attend regular follow-up appointments at the hospital. The timing for removal of internal fixation devices is determined based on the progress of fracture healing.

Outcome assessment

Perioperative parameters include: surgical duration (rounded to the nearest 10 min), intraoperative blood loss (rounded to the nearest 5 ml), and postoperative 24-hour drainage volume (rounded to the nearest 1 ml, recorded as 0 when there is fluid in the tube but not in the bag). Radiological parameters include the measurement of sagittal plane Cobb angle of the spine, vertebral wedge deformity index, both preoperatively, at 4 weeks postoperatively, and at the final follow-up for patients in each surgical group. The sagittal plane Cobb angle of the spine is defined as the angle between two perpendicular lines drawn from the upper endplate line of the injured vertebra to the lower endplate line of the lower adjacent vertebra. The vertebral wedge deformity index is the percentage representing the anterior height of the fractured vertebral body in relation to the posterior height of the fractured vertebral body. Functional assessment parameters include the use of VAS scores to evaluate the preoperative and 4-week postoperative lumbar pain levels of patients in each surgical group. Additionally, ODI scores are utilized to assess the preoperative and 4-week postoperative daily life functionality of patients in each surgical group. The occurrence of postoperative complications, including neurological injury, wound infection, and loosening or fracture of internal fixation devices, is recorded and analyzed for each surgical group.

Statistical analysis

Statistical analyses were executed using SPSS 22.0 software. Continuous data is depicted as mean ± standard deviation (SD). One-way ANOVA was employed for comparisons between different surgical groups for the same parameter. Variance analysis of repeated measures data was utilized for comparisons across different time points within each surgical group. Pairwise comparisons between groups were conducted using the Bonferroni method. For continuous data that did not follow a normal distribution, they were presented as median (P25, P75). Group comparisons were conducted using the Kruskal-Wallis H test. Pairwise comparisons between groups were performed using the Mann-Whitney U test with Bonferroni correction applied. Differences in categorical data among different surgical groups were assessed using the Chi-square test. In cases where the conditions for the chi-square test were not met, the Fisher's exact test was applied. Pairwise comparisons between groups were conducted using the Bonferroni method or Post hoc testing, with differences assessed based on adjusted standardized residuals. A significance level of $P < 0.05$ and an absolute value of standardized residuals greater than 3 were considered as indicating statistically significant differences. Significance thresholds were established as follows: $^{*}P < 0.05$ denoting statistical significance, $^{**}P < 0.01$ indicating high significance, $^{***}P < 0.001$ and $^{****}P < 0.001$ signifying utmost significance.

Results

Patient characteristics

There were no significant differences in patient age (P = 0.599), gender (P = 0.469), cause of injury (P = 0.833), fracture location (P = 0.643), and injury-to-surgery time (P = 0.795) among the various surgical groups, both in terms of overall comparisons and pairwise comparisons. (Table 1)

Table 1
Patient characteristics

Groups	Cases	Age	Sex		Causes			Injured segments			Injury to surgery (h)
			Male	Female	Accident	Fall	Bruised	T11/12	L1/2	L3/4	
TFSV	38	43.87 ± 8.72	20	18	17	12	9	13	19	6	54.24 ± 27.43
SFTV	53	43.49 ± 7.65	22	31	20	20	13	24	23	6	56.17 ± 27.77
STV	54	42.17 ± 9.58	22	32	26	18	10	27	20	7	52.74 ± 23.70
Statistics		F = 0.514	x^2=1.513		x^2=1.462			x^2=2.508			F = 0.229
P		0.599	0.469		0.833			0.643			0.795
P_1		>0.999	*a*		*a*			*a*			>0.999
P_2		>0.999									>0.999
P_3		>0.999									>0.999
P_1: TFSV compared with SFTV											
P_2: TFSV compared with STV											
P_3: SFTV compared with STV, the same below.											

Perioperative parameters

There was a statistically significant overall difference in surgical duration among the various surgical groups (P < 0.001). Specifically, the TFSV group had the shortest average surgical duration of 80.19 ± 11.18 minutes, while the SFTV group had the longest average surgical duration of 106.84 ± 8.73 minutes. There was a statistically significant overall difference in intraoperative blood loss among the various surgical groups (P = 0.023). However, there was no statistically significant difference in intraoperative blood loss between the TFSV group and the SFTV group (P>0.999). Likewise, there was no statistically significant difference in intraoperative blood loss between the SFTV group and the STV group (P = 0.169). Among them, the TFSV group had the highest intraoperative blood loss, with a median of 115 (107.5, 125) ml, while the SFTV group had the lowest intraoperative blood loss, with a median of 100 (75, 130) ml. There was a statistically significant overall difference in postoperative 24-hour drainage volume among the various surgical groups (P < 0.001). However, there was no statistically significant difference between the TFSV group and the STV group (P>0.999). Specifically, the STV group had the highest postoperative 24-hour drainage volume, with an average drainage of 11.22 ± 6.27 ml. Conversely, the SFTV group was the lowest, with an average drainage of 6.36 ± 5.36 ml. (Table 2)

Table 2
Perioperative parameters

Groups	Cases	Surgical duration (min)	Intraoperative blood loss (ml)	Postoperative 24h drainage volume (ml)
TFSV	38	106.84 ± 8.73	115(107.5, 125)	10.34 ± 6.02
SFTV	53	80.19 ± 11.18	100(75, 130)	6.36 ± 5.36
STV	54	90.74 ± 11.30	112.5(95, 135)	11.22 ± 6.27
Statistics		F = 69.431	H = 7.575	F = 10.081
P		<0.001	0.023	<0.001
P_1		<0.001	0.025	0.005
P_2		<0.001	>0.999	>0.999
P_3		<0.001	0.169	<0.001

Radiological parameters

There were no statistically significant differences in Cobb angles among the various surgical groups preoperatively. In comparison to the preoperative values, all surgical groups exhibited a significant improvement in Cobb angle at the 4-week postoperative assessment, with statistically significant differences observed (P_m=0.025, P_t<0.001, P_i=0.016). At the 4-week postoperative evaluation, there was a statistically significant overall difference in Cobb angle measurements among the various surgical groups (P < 0.001). However, when comparing the TFSV group and the STV group, there was no statistically significant difference (P>0.999). Both of these groups showed greater improvement in Cobb angles compared to the SFTV group. In comparison to the preoperative values, all surgical groups exhibited a significant improvement in the vertebral wedge deformity index at the 4-week postoperative assessment, with statistically significant differences observed. However, at the same time points, there were no statistically significant differences among the various surgical groups (P_m=0.289, P_t<0.001, P_i<0.001).

Since only approximately one-third of the patients provided data at the final follow-up, the analysis pertaining to the final follow-up data included only this subset of patients, while excluding outliers. At the final follow-up, there was a statistically significant overall difference in Cobb angle measurements among the various surgical groups (P < 0.001). However, when comparing the TFSV group to the STV group, there was no statistically significant difference (P = 0.194). Both of these groups exhibited smaller Cobb angle compared to the SFTV group. At the final follow-up, there were no statistically significant differences in the vertebral wedge deformity index among the various surgical groups (P = 0.299). (Table 3)

Table 3
Radiological parameters

Groups	Cases	Cobb(°)			Vertebral wedge deformity index (%)		
		Preoperative	4w Postoperative	End of follow-up *b*	Preoperative	4w Postoperative	End of follow-up *b*
TFSV	38	27.65 ± 5.16	11.22 ± 1.52	13.06 ± 1.32	42.07 ± 7.64	22.93 ± 5.00	20.36 ± 5.98
SFTV	53	27.11 ± 5.19	14.25 ± 1.55	15.08 ± 1.33	43.54 ± 6.71	22.57 ± 4.71	20.62 ± 4.45
STV	54	26.42 ± 4.74	11.45 ± 1.50	12.48 ± 1.34	44.06 ± 7.18	23.85 ± 4.87	21.48 ± 4.81
F		0.31	51.727	21.325	0.413	0.866	0.254
P		0.969	<0.001	<0.001	0.663	0.425	0.777
P_1		>0.999	<0.001	0.001	>0.999	>0.999	>0.999
P_2		>0.999	>0.999	0.194	>0.999	>0.999	>0.999
P_3		>0.999	<0.001	<0.001	>0.999	0.684	>0.999
F_m		3.857		282.109	1.262		1.225
P_m		0.025		<0.001	0.289		0.299
F_t		1077.494		0.949	59.442		469.52
P_t		<0.001		0.399	<0.001		<0.001
F_i		4.352		8.04	228.979		1.324
P_i		0.016		0.003	<0.001		0.28

m: main, t: time, i: interaction, the same blow.

Functional assessment parameters

In comparison to the preoperative values, all surgical groups showed a significant improvement in VAS scores at the 4-week postoperative assessment, with statistically significant differences observed. However, at the same time points, there were no statistically significant differences among the various surgical groups (P_m=0.312, P_t<0.001, P_i<0.001). In comparison to the preoperative values, all surgical groups exhibited a significant improvement in ODI scores at the 4-week postoperative assessment, with statistically significant differences observed. However, at the same time points, there were no statistically significant differences among the various surgical groups (P_m=0.924, P_t<0.001, P_i=0.762). (Table 4)

Table 4
Functional assessment parameters

Groups	Cases	VAS score		ODI score	
		Preoperative	4w Postoperative	Preoperative	4w Postoperative
TFSV	38	7.63 ± 1.02	1.18 ± 0.80	83.58 ± 4.25	3.13 ± 1.30
SFTV	53	7.60 ± 1.06	0.98 ± 0.77	83.64 ± 4.61	2.87 ± 1.19
STV	54	8.04 ± 0.80	1.26 ± 0.78	83.93 ± 3.95	3.28 ± 1.35
F		1.804	1.708	0.092	1.395
P		0.172	0.188	0.912	0.251
P_1		>0.999	>0.999	>0.999	>0.999
P_2		0.368	0.804	>0.999	>0.999
P_3		0.186	0.229	>0.999	>0.999
F_m		1.165		0.079	
P		0.312		0.924	
F_t		316.35		39799.209	
P		<0.001		<0.001	
F_i		1751.897		0.207	
P		<0.001		0.762	

In each surgical group, there was a statistically significant difference when comparing VAS or ODI scores before surgery and at 4 weeks postoperatively. (F = 1018.306, P<0.001; F = 1157.235, P<0.001; F = 2012.378, P<0.001), (F = 12471.568, P<0.001; F = 15234.869, P<0.001; F = 20177.837, P<0.001)

Complications

All cases underwent surgery without complications, including neurological dysfunction, infection, or postoperative loosening or fracture of screws. It is worth noting that, at the final follow-up, in the TFSV group, 3 out of 18 follow-up patients (16.67%) experienced an increase in sagittal plane Cobb angle greater than 10 degrees compared to the 4-week postoperative. In the SFTV group, 1 out of 18 follow-up patients (5.56%) had an increase. All four of these patients were elderly females. The overall difference was not statistically significant (P = 0.833). (Table 5)

Table 5
Complications

Groups	Cobb increased over 10° at the end of follow-up	Normal	Total
TFSV	3	15	18
SFTV	1	17	18
STV	0	20	20
Total	4	52	56
P			0.833

Discussion

Posterior pedicle screw fixation is a commonly employed method for treating thoracolumbar burst fractures. It serves the purpose of expanding and realigning, effectively restoring vertebral height and physiological spinal curvature, thereby achieving immediate stability. The use of TFSV is a relatively traditional surgical approach. However, due to its longer fixed segment, the fixation effect is not precise, and it is prone to postoperative pain and long-term complications[15]. The reasons for this may include the following aspects: (1) The thoracolumbar spine serves as the transition point between the thoracic and lumbar regions, with different levels of mobility. The stress of trunk movement is concentrated in this region [14]. Additionally, the physiological kyphosis in the thoracic spine and lordosis in the lumbar spine lead to a concentration of load-bearing stress in this area, resulting in higher stress on the internal fixation system and making it prone to failure[16]. (2) In segmental fixation, stress is concentrated between the upper and lower pedicle screws, with a significant portion of the load transmitted through the pedicle screws and bone interfaces[17]. This makes it susceptible to metal fatigue, leading to internal fixation failure. As a result, the injured vertebral body may lose its ability to maintain its reduced position, leading to collapse, height loss, and even screw or rod breakage, affecting postoperative spinal stability and resulting in postoperative kyphotic deformity[18]. (3) Although the posterior pedicle screw fixation system achieves realignment and fixation of the fractured vertebral body, it does not restore the previously disrupted trabecular bone to its original "uniform" state. Even after expansion, there may still be intravertebral gaps, resulting in a "shell-like" appearance of the vertebral body.

To overcome the limitations of the above surgical approach, many researchers have attempted various alternative procedures[19, 20]. Among them, the STV is a recent innovation[21]. This method enhances the biomechanical stability by placing pedicle screws within the injured vertebra, reducing the loss of correction degree. Simultaneously, it reinforces the strength of the internal fixation system, providing better conditions for fracture healing and improving the stress distribution within the internal fixation system. It also safeguards the damaged vertebral body and intervertebral disc, increases the grip of the internal fixation system, and reduces movement at the bone-metal interface. The placement of pedicle screws within the injured vertebra can maintain the continuity of the pedicle roots with the articular processes and transverse processes, creating a three-plane effect[22], thereby providing a more effective stabilization of the injured vertebra. Additionally, it can distribute the stress load from the injured vertebra to the posterior structures of adjacent vertebrae, reducing stress concentration and the hanging effect, resulting in reduced postoperative vertebral height loss and minimizing the occurrence of screw or rod breakage[23]. Based on the modification of this surgical technique, a subsequent development was the SFTV. One significant advantage of this modified approach is the reduced number of fixed segments, resulting in minimal surgical trauma, reduced intraoperative bleeding, and shorter surgical duration. Furthermore, this technique allows for the maximum preservation of lumbar mobility, alleviating postoperative stiffness and reducing the occurrence of postoperative pain[24]. However, it is only suitable for fractures with intact pedicles and only one-sided burst endplates on the injured vertebra, and its reduction effect is inferior to the six-screw fixation technique, limiting its applicability[25].

The results of our study indicate that, in terms of the height restoration, improvement in segmental kyphosis, canal compromise and restoring the sagittal plane Cobb angle of the spine, all three surgical techniques can achieve the desired outcome, although the SFTV technique's reduction effect is slightly less pronounced compared to the other two techniques. Regarding the restoration of the shape of the fractured vertebral body, there are no significant differences among the three surgical techniques. In terms of functional assessment, patients in all three surgical groups showed good recovery at the 4-week postoperative follow-up. Postoperatively, vertebral healing was essentially stable at 12 months, with minimal changes in Cobb angles. Therefore, we combined and analyzed the data from the final follow-up without distinguishing time points. At both the 4-week postoperative assessment and the final follow-up, the SFTV group showed differences in Cobb angle compared to the other two groups, indicating limitations in this technique's reduction aspect. At the final follow-up, among the 18 follow-up patients in the TFSV group, 3 had Cobb angles increase by more than 10 degrees (16.67%), while in the SFTV group, among the 18 follow-up patients, 1 had a Cobb angle increase of more than 10 degrees (5.56%). In contrast, in the STV group of 20 follow-up patients, the Cobb angles were mostly within the normal range. Although the conclusion may be subject to chance due to the limited number of patients in the final follow-up, it to some extent confirms the limitations of TFSV and its inability to guarantee long-term outcomes. The four outlier patients were all elderly females. Although bone density-related data were not collected in this study, the abnormal increase in Cobb angles postoperatively in elderly female patients strongly suggests that osteoporosis is one of the risk factors for long-term complications following burst fractures[26–29]. Previous studies have indicated that PKP is ineffective for height restoration and improvement in segmental kyphosis, therefore cement augmentation or intelligently inflatable reduction combined with SFTV or STV treatment is the first choice for elderly patients with osteoporotic thoracolumbar burst fractures[30, 31]. This information can also guide the surgical selection for patients at high risk of postoperative complications following thoracolumbar burst fractures.

The limitations of our study include its small patient population, short follow-up period, and retrospective design. Future studies with a prospective randomized controlled study enrolling more patients through a long-term follow-up period are needed to compare TFSV with SFTV and STV more reliably and objectively.

Conclusion

All three posterior approaches can provide satisfactory treatment outcomes for patients with thoracolumbar burst fractures. Among them, TFSV is less commonly used due to its greater surgical trauma, higher postoperative complication rate, less certain long-term outcomes, and a higher likelihood of secondary Cobb angle increase. SFTV is often the preferred choice because of its minimal surgical trauma, fewer fixed segments, and reliable fixation[32]. However, its reduction effect is not as effective as the other two techniques, and it requires intact pedicles and one-side endplates of the injured vertebra. Therefore, it is suitable for patients with milder injuries and less Cobb angle increases. STV, on the other hand, has a broader range of applications. Based on these findings, we recommend that for patients with thoracolumbar burst fractures requiring open reduction and internal fixation, SFTV should be chosen whenever possible to ensure surgical effectiveness. Patients who are not suitable for SFTV should consider STV, and if necessary, they can undergo PVP or PKP procedures[9, 31].

Declarations

Ethics approval and consent to participate

This study was approved by the Ethics Committee of the Western Theater Air Force Hospital. Due to the retrospective nature of the study and its long duration, the ethics committee waived the informed consent of all participants as long as their privacy was fully protected.

Consent for publication

Approved for publication by Western Theater Air Force Hospital.

Availability of data and materials

The datasets generated and analyzed during the current study are not publicly available due we did not obtain the informed consent of all participants, but are available from the corresponding author on reasonable request.

Conflict of interest

The authors have declared that no conflict of interest.

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Authors’ contributions

Tianxiong Wang and Bingang Wang completed the operation. Yuheng Zhang completed the manuscript and provided the funding support. Rui Wang performed the statistical analysis. Shizhan Chen and Bingang Wang revised the manuscript initially, and Yongjie He performed the case data collection.

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