Effective Method of Pedicle Screw Fixation in Patients with Neurologically Intact Thoracolumbar Burst Fractures: A Systematic Review of Studies Published Over the Last 20 Years

Andrey Grin
Department of Neurosurgery, Sklifosovsky Research Institute for Emergency Medicine, Moscow, Russia
https://orcid.org/0000-0003-3515-8329

Vasiliy Karanadze
Department of Neurosurgery, Sklifosovsky Research Institute for Emergency Medicine, Moscow, Russia
https://orcid.org/0000-0003-0180-9154

Anton Kordonskiy
Department of Neurosurgery, Sklifosovsky Research Institute for Emergency Medicine, Moscow, Russia
https://orcid.org/0000-0001-5344-3970

Aleksandr Talypov
Department of Neurosurgery, Sklifosovsky Research Institute for Emergency Medicine, Moscow, Russia
https://orcid.org/0000-0002-6789-8164

Ivan Lvov
dr.speleolog@gmail.com

Department of Neurosurgery, Sklifosovsky Research Institute for Emergency Medicine, Moscow, Russia
https://orcid.org/0000-0003-1718-0792

Systematic Review

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Abstract

Objective: To conduct a systematic review of studies focusing on various PSF methods for neurologically intact burst fractures of the thoracic and lumbar spine (TLFS) and identify the most effective and safe approach among them.

Methods. Systematic review was conducted following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. The study was registered in the PROSPERO (№ CRD42024531093). The inclusion criteria for articles in the systematic review were as follows: 1) publication date between January 1, 2004, and December 31, 2023; 2) availability of the full-text version of the article in English; 3) fracture type A3 or A4 according to the AOSpine classification, or types A, B, or C burst fractures according to the F. Denis classification, or direct indication by the author of the presence of a "burst" fracture without its classification; 4) absence of neurological deficit; 5) patient age over 18 years; 6) description of treatment outcomes or complications; 7) follow-up period of 12 months for patient samples.

Results. In total, the 70 articles presented treatment results for 122 groups of patients were included. Statistical analysis demonstrated the advantages of short-segment fixation in terms of operation duration and intraoperative blood loss ($p = 0.001$ and < 0.001, respectively). It was also found that the frequency of deep infection was significantly higher with extensive fusion compared to other PSF methods ($p = 0.043$). Percutaneous pedicle screw fixation (PSF) was performed in patients with lower body compression rate and kyphotic deformity values ($p = 0.043$), had less potential for their correction ($p = 0.004$), but significantly reduced blood loss ($p = 0.011$), operation duration ($p < 0.0001$), and hospitalization period ($p < 0.0001$). Statistical analysis did not reveal significant advantages of using additional intermediate screws in patients undergoing short-segment PSF.

Conclusions. The optimal surgical treatment method for neurologically intact thoracolumbar burst fractures is short-segment, 4-screw pedicle screw fixation. The use of posterior lateral fusion in this context may increase the deep infection rate without reducing the frequency of implant-related complications or affecting long-term treatment outcomes. Percutaneous approach is the preferred technique; however, in patients with severe kyphotic deformities, its lower reduction capabilities should be considered during surgical planning. The application of intermediate screws in patients with neurologically intact thoracolumbar burst fractures did not demonstrate any significant advantages. Removal of the fixation system did not lead to a significant reduction in implant-related complications or improvement in quality of life.

Introduction

The choice of treatment method for patients with neurologically intact burst fractures of the thoracic and lumbar spine (TLBF) is currently far from definitive. The effectiveness of conservative therapy in such patients demonstrates that adequate immobilization of the injured segment can not only achieve fracture

consolidation but also reduce the degree of spinal canal stenosis due to resorption of bony fragments [1]. If conservative therapy is not feasible for such patient, internal immobilization of the injured segment using metal fixators appears to be the optimal treatment option. The choice of approach in interventions for patients with TLBF currently does not pose significant difficulties. Anterolateral approaches are optimal for performing anterior decompression, as well as for patients with severe kyphotic deformities [2]. A meta-analysis by Hinojosa-Gonzalez et al. [3] demonstrated equal effectiveness of anterolateral and posterior approaches in the surgery of TLBF, with a significant reduction in operation time, blood loss, and hospitalization periods for patients undergoing standard pedicle screw fixation (PSF). Regarding the selection of a specific PSF method, the literature contains numerous prospective studies, as well as systematic reviews and meta-analyses. A significant drawback of these studies is the high degree of heterogeneity among patient groups due to the inclusion of both patients with complicated trauma and those with distraction or translational injuries. We did not find a systematic study dedicated to the choice of intervention method in patients with uncomplicated "burst" TLFS fractures in the literature at present.

Objective

To conduct a systematic review of studies focusing on various PSF methods for neurologically intact burst fractures of the thoracic and lumbar spine (TLFS) and identify the most effective and safe approach among them.

Material and methods

Study selection

Systematic review was conducted following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines [4]. The study was registered in the PROSPERO (№ CRD42024531093).

The search strategy used in the PubMed database included the following keywords: (Lumbar vertebrae [MeSH] OR Thoracic vertebrae [MeSH] OR spine [MeSH] OR Thoracolumbar [TIAB] OR thoraco-lumbar [TIAB] OR thoraco lumbar [TIAB] OR burst [Title]) AND (Injur* [TIAB] OR trauma* [TIAB] OR fractur* [TIAB] OR dislocation* [TIAB]) NOT animal [MeSH] NOT comment [PT] NOT letter [PT] NOT editorial [PT] NOT news [PT] NOT “newspaper article” [PT] NOT osteoporosis [MH] NOT osteoporotic fractures [MH] NOT osteoporo* [TITLE] NOT spinal neoplasms [MH] NOT tumor* [TITLE] NOT malignan* [TITLE].

The inclusion criteria for articles in the systematic review were as follows: 1) publication date between January 1, 2004, and December 31, 2023; 2) availability of the full-text version of the article in English or Russian; 3) fracture type A3 or A4 according to the AOSpine classification, or types A, B, or C burst fractures according to the F. Denis classification, or direct indication by the author of the presence of a "burst" fracture without its classification; 4) absence of spinal cord or nerve root injury at the time of patient admission to the hospital; 5) patient age over 18 years; 6) description of treatment outcomes or complications developed in the study; 7) minimum follow-up period of 12 months for patient samples. All

articles that did not meet these criteria were excluded from the study. The search and selection algorithm for articles is presented in Fig. 1.

Data collection

The data from each article were recorded in the corresponding cells of the table. If the relevant information was not available in the text of the article, the cells were marked as "n/a" (not available). Basic information included sample size, average patient age, gender distribution, diagnosis, and mechanism of injury. The main data block included: PSF execution method (percutaneous, midline, or paramedian approaches), number of screws, fusion method, implant removal timeframe, radiological indicators at admission, post-intervention, and during final assessment, length of hospital stay, average duration of final follow-up, severity of pain syndrome using the Visual Analogue Scale (VAS), and quality of life at final follow-up according to the Oswestry scale. When studying radiological indicators, the degree of kyphotic deformation of the segment (Cobb angle), the degree of compression of the anterior vertebral body (anterior vertebral body compression percentage - AVBCP) relative to unaffected segments, and the degree of spinal canal stenosis based on the mid-sagittal diameter were recorded [5].

Statistical analysis

Statistical analysis was performed using the PC STATISTICA software (Version 10) (StatSoft@ Inc., USA). The normality of data distribution was assessed using the Shapiro-Wilk test. Comparison of continuous data with non-normal distribution was conducted using the Mann-Whitney U test or the Kruskal-Wallis test. Statistical hypothesis testing was performed at a critical significance level of $p = 0.05$.

Results

Article selection

The initial search in the PubMed database identified 1255 articles. After applying filters for age and language, the remaining abstracts were screened. As a result of the initial search, 189 studies were selected for full-text review. Of these, 70 articles met the necessary criteria and were included in the present study (Fig. 1). In total, these studies reported treatment data for 3174 patients. Depending on the specifics of the surgical intervention, most authors divided their sample into 2 or more groups in their studies. In total, the 70 articles presented treatment results for 122 groups of patients with neurologically intact TLBF. For 103 groups of patients, a specific level of injury was indicated, while for the remaining 19 groups, the level of injury was designated as thoracolumbar junction (TLJ) without specifying specific vertebrae. Of the 103 patient groups, 68 described injuries at the Th10-L2 or Th11-L2 level, 32 included TLJ and the entire lumbar spine, and 3 articles focused only on L1-L4 vertebrae.

Gender distribution was reported in 64 articles (2917 patients). There were 1877 males (64.3%) and 1040 females (35.7%). The median value for average age across all studies was 42 years. The mechanism of

injury was specified in 37 studies (1877 patients). The main causes of TLFS injury were falls from height (47.8%) and road traffic accidents (39.4%).

Analysis of PSF extension and fusion application

The extent of PSF was specified for 122 groups of patients. Most patients (101 groups, 2700 individuals) underwent short-segment PSF with immobilization of two adjacent motion segments. In 15 groups (334 patients), PSF was performed for three or more segments. Monosegmental PSF was performed in 6 groups (140 patients).

Posterior fusion was performed using two techniques. Most patients (52 groups, 1231 individuals) underwent posterior lateral fusion (PLF) by decorticating the posterior structures of the corresponding segments with subsequent placement of allograft or autograft bone grafts. In 2 groups (37 patients), interbody fusion was performed using the TLIF technique. E3A without fusion was performed in 68 groups (1906 patients). T

The duration of PSF was indicated for 103 groups of patients. Among them, PSF was removed on average 12 months after the intervention for 31 groups (894 patients). In 74 groups (1711 patients), PSF was not removed throughout the entire follow-up period.

Simultaneously, the extent of fixation, application of fusion, and indication for removal or non-removal of PSF were specified for 94 patient samples (2620 individuals), allowing for the formation of 5 comparison groups. Statistical analysis demonstrated the advantages of short-segment fixation in terms of operation duration and intraoperative blood loss ($p = 0.001$ and < 0.001, respectively). It was also found that the frequency of deep infection was significantly higher with extensive fusion compared to other PSF methods ($p = 0.043$). No significant differences were found for other parameters (Table 3).

Analysis of PSF methods

Short-segment PSF without fusion was performed using three types of approaches: midline (22 groups, 605 patients), paramedian (8 groups, 323 patients), and percutaneous (33 groups, 921 patients). It was found that percutaneous PSF was performed in patients with lower AVBCR and kyphotic deformity values, had less potential for their correction, but significantly reduced blood loss, operation duration, and hospitalization period (Table 4).

Intermediate screw application

For 81 patient groups undergoing short-segment PSF, the presence or absence of intermediate screws at the level of the fractured vertebra was noted in the article text. Specifically, in 29 groups, intermediate screws were used (872 patients), while in 42 groups (1417 patients), standard 4-screw PSF was performed. Considering the limitations of minimally invasive techniques identified earlier, the use of intermediate screws was analyzed separately for patients undergoing percutaneous fixation and PSF via posterior midline approach. Statistical analysis did not reveal significant advantages of using additional intermediate screws in patients undergoing short-segment PSF (Tables 5 and 6).

Decompression in patients with neurologically intact TLBF

Out of all 134 patient groups, authors applied laminotomy or laminectomy for fragment removal or repositioning maneuvers only in 3 groups. In the remaining groups, at the time of patient admission, the median value for the average spinal canal compression rate was 38.65% [Q1-Q3, 32.1–47.0]. By the time of final assessment, this indicator had almost halved, reaching 20.8% [Q1-Q3, 14.7–23.7].

Discussion

Despite the abundance of publications addressing spinal injury surgical treatments, certain aspects remain contentious, necessitating further research. One of the most relevant questions concerns the surgical treatment of patients with neurologically intact TLBF. While the approach is straightforward and widely accepted in cases involving neurological deficits (decompression, restoration of spinal column alignment, and fixation of the injured segment [80]), questions arise when no neurological deficit is present. In contemporary literature, there is no unanimous answer to these questions. A systematic review or meta-analysis is the most compelling approach, as it allows for compiling results from included studies to enhance the level of evidence for their conclusions. In the context of TLBF, we found 11 systematic reviews and meta-analyses exploring various aspects of PSF [81–91]. However, these meta-analyses have two significant drawbacks. Firstly, they all include groups with neurological deficit. Such patients often have worse indicators of kyphotic deformity, vertebral body compression, and spinal canal stenosis, as well as potentially higher complication rates and lower rehabilitation potential. Secondly, they include a small number of studies, with an average of 5–6 comparative studies compiled by the authors. These drawbacks can significantly influence the results and lead to conflicting conclusions. At the time of writing this review, we did not find any systematic studies in the literature allowing for the selection of the optimal surgical treatment method specifically for neurologically intact TLBF.

The most important questions in our study were the extent of PSF and the necessity of performing bone fusion via the posterior approach. According to the meta-analysis by Ituarte et al. [91], more extensive PSF in TLFS contributed to less postoperative kyphosis progression and reduced the frequency of implant-associated complications. Regarding the necessity of fusion, three meta-analyses were previously published [81–83]. The authors of the most recent study [82] concluded, based on the comparison of only 6 patient groups, that there were no advantages of posterior lumbar fusion (PLF) in long-term outcomes. In our review, we demonstrated that on one hand, PLF significantly prolongs the operation and increases the risk of infectious complications in the case of prolonged PSF, and on the other hand, it significantly does not affect the degree of kyphotic deformity correction and restoration of fractured vertebra height.

The question of temporary PSF was investigated in two meta-analyses [84, 90]. Both authors concluded that removing the fixation system leads to improved quality of life in the postoperative period without subsequent deterioration of radiological indicators. It should be noted that these conclusions could also be influenced by the number of included studies and data processing methodology. For instance, Kweh et

al. [84] used only two studies to construct forest plots for the VAS and Oswestry scales, while Visagan et al. [90] solely relied on descriptive statistical methods. In the present study, when comparing temporary and permanent short-segment PSF, we used results from 28 and 19 articles, respectively. Authors of the included studies justified the removal of PSF systems by the need to prevent implant breakage or pool-out. However, no statistically significant differences were found in the frequency of implant-related complications, loss of achieved kyphosis correction, or quality of life at the time of final assessment according to the VAS and Oswestry scales between groups with permanent and temporary PSF (Table 3).

The choice of approach is also crucial. Four published comparative meta-analyses indicate the advantages of percutaneous fixation not only in reducing operation time, blood loss, and postoperative hospital stay [85, 88, 89, 92] but also in decreasing the frequency of infectious complications [85, 88], correcting kyphotic deformity [88, 92], and improving the quality of life at the final follow-up [85, 92]. In our study, we found that short-segment percutaneous fixation significantly reduces intraoperative blood loss, operation duration, and average hospital stay compared to midline approach (Table 4). However, it should be noted that percutaneous fixation was performed on patients with less kyphotic deformity and vertebral body compression, indicating less severe injury. Additionally, according to data obtaned, the degree of kyphotic deformity correction with the percutaneous method was significantly lower than with open midline approach. No significant differences were found in VAS and Oswestry scores at the final follow-up, as well as in the frequency of infectious or implant-related complications between minimally invasive and open PSF groups. These results suggest potentially insufficient repositioning capabilities of percutaneous fixation using polyaxial screws, as utilized by most authors. Some studies indicated the use of monoaxial screws and specialized fracture reduction systems; however, their numbers were insufficient to conduct a statistically significant comparison within this systematic review.

The use of additional screws at the fracture level is currently debatable and addressed by two meta-analyses [86, 87]. Both authors indicate an increase in the degree of kyphotic deformity correction and fractured vertebra height, as well as a decrease in the frequency of implant-related complications in patients with additional screws. It is worth noting that both meta-analyses included groups not only with spinal cord injuries but also with translational and distraction injuries (AOSpine types B and C). We did not find any conclusions or recommendations regarding the use of additional screws in patients with neurologically intact TLBF in the literature. In our study, we did not find a statistically significant impact of additional screws on any of the investigated parameters, which may be due to the absence of patients with distraction or translational injuries in the samples, the correction of which poses a more challenging task.

The question of the necessity of laminectomy or laminotomy in patients with TLBF has not been addressed by any systematic review or meta-analysis. Most authors did not perform decompression even if the spinal canal stenosis reached 50%. Intervention in the spinal canal was performed only in 2 studies for the removal or repositioning of bone fragments. Nevertheless, simple internal immobilization of the injured segment proved to be sufficient to achieve good radiological results. Patients exhibited lysis of bone fragments with a regression of spinal canal compression by almost half, which corresponds to the

result of conservative therapy for TLBF [1] and once again demonstrates the lack of necessity for spinal canal decompression in such patients.

Study limitations.

Limitation of this review is the grouping of the majority of included studies into one category of A3 and A4 fractures according to the AOSpine classification, as well as types A, B, and C injuries according to F. Denis classification. Subdivision of "burst" fractures of the thoracic and lumbar spine into subtypes would have allowed for a more precise analysis of the results of various spinal fixation techniques.

Conclusion

The optimal surgical treatment method for neurologically intact thoracolumbar burst fractures is short-segment, 4-screw pedicle screw fixation. The use of posterior lateral fusion in this context may increase the deep infection rate without reducing the frequency of implant-related complications or affecting long-term treatment outcomes. Percutaneous approach is the preferred technique; however, in patients with severe kyphotic deformities, its lower reduction capabilities should be considered during surgical planning. The application of intermediate screws in patients with neurologically intact thoracolumbar burst fractures did not demonstrate any significant advantages. Additionally, removal of the fixation system did not lead to a significant reduction in implant-related complications or improvement in quality of life. Further comparative studies of different spinal fixation techniques with a high level of evidence should be conducted in the future to form treatment recommendations in corresponded protocols.

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Tables

Table 3 Comparison of patient groups based on the fusion extension.

	PSF + PLF			Short-segment PSF only		
	Long-segment (n=13)	Short-segment (n=30)	Mono-segmental (n=5)	Permanent (n=19)	Temporary (n=27)	
Surgery duration, minutes*	164.4	136	90	95.4	85.8	0.001
Intraoperative blood loss, ml*	459.7	425	180	133.5	106.2	<0.001
Cobb angle at admission, 0*	18.9	17.4	17.4	19.6	17.7	0.782
AVBCR at admission, %*	44.3	39.6	35.1	36.9	40.5	0.382
Intraoperative Cobb angle correction, 0*	12	12.5	11	9.5	12.7	0.333
Postoperative reducing of AVBCR, %*	35.5	23.5	22.9	25.6	32.7	0.368
Length of hospital stay, days*	10	10.8	-	5.2	10.8	1.000
Follow-up, months*.	34.6	26.5	24.7	24	24	0.171
Cobb angle increasing at final follow-up*, 0	3.7	3.7	3	1.8	3.1	0.444
AVBCR increasing at final follow-up*, %	5	4	6.7	6.6	4.1	0.450
Superficial wound infection rate*, %	0 [0 – 3.7]	0 [0 – 1.4]	0 [0 – 2.7]	0	0 [0 – 1.6]	0.464
Deep wound infection rate*, %	0 [0 – 5.6]	0	0	0	0	0.031
Implant-related complications rate*, %	0 [0 – 3.2]	0 [0 – 5.7]	0	0 [0 – 1.4]	0 [0 – 4.8]	0.744
Fusion rate**, %	100 [97.1-100]	100	-	-	-	0.681
Fracture healing rate, %**	-	-	-	92.9 [67.9-100]	100	0.260
VAS*	2.2	1.9	1	2.3	2.1	0.173
Oswestry*	14.5	15.5	-	15	12	0.183

* Kruskal-Wallis test

** Mann-Whitney U test

PSF, pedicle screw fixation; PLF – posterior lateral fusion.

Table 4 Comparison of patient groups based on the approach type

	Paramedian approach (n=8)	Percutaneous approach (n=31)	Midline approach (n=22)	p*
Surgery duration, minutes	68.7	79.7	101	0.011
Intraoperative blood loss, ml	98.7	75	236.1	< 0.001
Screw malposition rate, %	4.3	2.6	0.4	0.495
	[3.0 – 10.1]	[0 – 5.8]	[0 – 15.6]	
Cobb angle at admission, ^{0}	20.9	13.7	19	0.043
AVBCR at admission, %	36.3	32.7	37.8	0.059
Intraoperative Cobb angle correction, ^{0}	14.6	8.3	12.7	0.004
Postoperative reducing of AVBCR, %	32.5	24.1	31.2	0.035
Length of hospital stay, days	8.9	4.9	12.8	< 0.001
Superficial wound infection rate, %	0	0	0	0.176
	[0 – 1.2]	[0 – 0.6]		
Deep wound infection rate, %	0	0	0	0.449
Implant-related complications rate, %	0	0	0	0.841
	[0 – 8.7]	[0 – 1.7]	[0 – 3.9]	
Follow-up, months.	24	21.9	18	0.952
VAS	2.1	1.5	2.1	0.468
Oswestry	6	12.1	17	0.236

*** Kruskal-Wallis test**

Table 5 Comparison of patient groups based on the use of intermediate screws for percutaneous pedicle screw fixation technique.

	Intermediate screws		p*
	Yes (n=12)	No (n=18)	
Surgery duration, minutes	68.8	78.9	0.824
Intraoperative blood loss, ml	60	79	0.204
Cobb angle at admission, ^{0}	18.2	11.9	0.421
AVBCR at admission, %	34.3	33.4	0.899
Intraoperative Cobb angle correction, ^{0}	7.4	9.7	0.845
Length of hospital stay, days	3	4.8	0.114
Superficial wound infection rate, %	0 [0 – 1.3]	0	0.251
Deep wound infection rate, %	0	0	0.775
Implant-related complications rate, %	0 [0 – 1.4]	0 [0 – 1.4]	0.352
Follow-up, months.	20.9	24	0.664
Cobb angle increasing at final follow-up, ^{0}	1	2.6	0.570
VAS	1.1	2.4	0.111
Oswestry	15	13.5	0.382

* Mann-Whitney U test

Table 6 Comparison of patient groups based on the use of intermediate screws for open pedicle screw fixation technique.

Параметр	Intermediate screws		p*
	Да (n=19)	Нет (n=32)	
Surgery duration, minutes	123	132	0.597
Intraoperative blood loss, ml	276.5	380	0.495
Cobb angle at admission, ^{0}	18.3	18.2	0.421
Intraoperative Cobb angle correction, ^{0}	13	12.6	0.845
Postoperative reducing of AVBCR, %	31.1	32.1	0.920
Length of hospital stay, days	9.4	12.2	0.114
Superficial wound infection rate, %	0	0 [0 – 2.5]	0.294
Deep wound infection rate, %	0	0	0.821
Implant-related complications rate, %	0 [0 – 2.8]	3.3 [0 – 5.7]	0.498
Follow-up, months.	26.5	24	0.616
Cobb angle increasing at final follow-up, ^{0}	3	4	0.570
AVBCR increasing at final follow-up, %	4.5	5.6	0.743
VAS	1.9	1.8	0.864
Oswestry	15	16.3	0.383

* Mann-Whitney U test

Figures

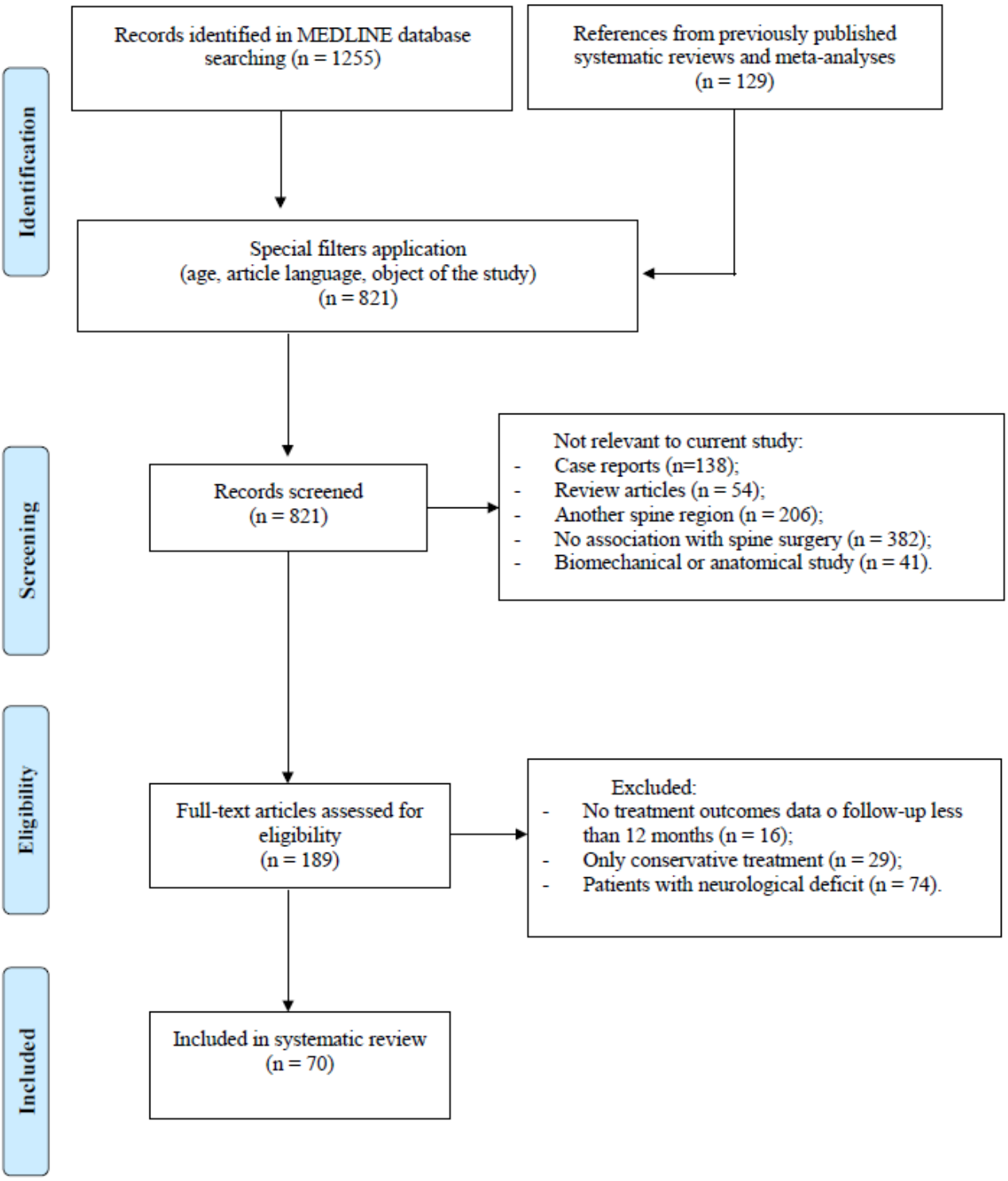

Figure 1

PRISMA Flowchart for Study Selection