ANALYSIS OF TECHNICAL OPTIONS FOR DECOMPRESSION AND STABILIZATION SURGERY FOR INJURIES OF THE LOWER THORACIC AND LUMBAR SPINE: A SYSTEMATIC REVIEW OF THE LITERATURE

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The objective of this systematic review was to analyze the clinical efficacy of various technical options for surgical treatment of patients with injuries to the lower thoracic and lumbar spine. The review includes 57 studies published in 2001–2022, which were selected from the main medical databases – PubMed, Medline, and The Cochrane Database of Systematic Reviews. In these publications, five options for surgical intervention were identified, the clinical effectiveness of which was determined by the degree of regression of neurological disorders, the quality of the achieved reposition, the amount of loss of correction within two years after surgery, the number of complications, the duration of operations, and the amount of blood loss. For pairwise comparison between groups, the Kruskal – Wallis test was used for several independent samples, based on the initial determination of the normality of data distribution in groups. To determine the differences between the parameters before and after the operation, the Wilcoxon test was used for two dependent samples. Differences were considered statistically significant at $p < 0.05$. An analysis of the literature data showed that there are no differences in the dynamics of neurological recovery in patients with spinal cord injury in the thoracic or lower lumbar spine when using five different types of surgical treatment. There are also no differences in the quality of correction of kyphotic deformity of injured spinal motion segments between all studied groups. Statistically significant lower loss of deformity correction is noted in patients who underwent one-stage circumferential decompression through posterolateral approach and decompression through combined approaches. Notably, operations performed through isolated posterior or anterior approaches have comparable values of correction loss. Operations with decompression of the dural sac through the posterior approaches are characterized by a significantly shorter time of surgical intervention than operations with decompression through the anterior and combined approaches. The smallest volume of blood loss is observed during surgery with decompression through isolated posterior approaches. The largest volume of blood loss is in the group with posterolateral approach and one-stage circumferential decompression. Surgical interventions through posterior approach have a statistically significant lower complication rate than operations that include the anterior stage.

Key Words: thoracic and lumbar spine, injury, surgery treatment, systematic review.
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The main objectives of surgical treatment of injuries of the lower thoracic and lumbar spine are decompression of the dural sac, correction of anatomical relationships in the affected spinal motion segment (SMS), reliable spinal stabilization, and restoration of the support ability of the anterior parts of the affected SMS [1, 2].

These challenges involve the use of various technical options for decompression and stabilization procedures. Posterior approach surgeries include laminectomy to perform posterior decompression, reposition of injured SMS, and transpedicular fixation (TPF). Nevertheless, the full restoration of the supporting function of the anterior and middle columns of the SMS is impossible to achieve with the help of such a technique, resulting in instability in the conditions of the performed laminectomy [3]. Anterior approach surgeries have a number of advantages. Firstly, it is possible to perform anterior decompression directly in the area of spinal cord compression. Secondly, optimal conditions appear for the placement of body-substituting implants of an adequate size, allowing for full restoration of the support ability of the anterior and middle columns and achieving a reliable bone block [4]. Nevertheless, the possibilities of this surgical option are limited for injuries of types B and C according to the AOSpine classification, in considerable dislocations in the injured SMS, as well as in the posterior variant of dural sac compression [5, 6]. Combined surgical interventions provide circumferential decompression, 360° stabilization, and also prove to be the best indicators of correction of anatomical relationships with minimal subsequent loss of correction [7, 8]. However, it is vital to consider their limitations: long surgery duration, a volume of intraoperative blood loss, a high injury rate of two approaches, and the risk of damage to internal organs and great vessels [9].

With increased attention being paid to the development of a recommendation base for providing assistance to patients with spinal injuries, evidence of the superiority of some surgical treatment options over others is best traced through systematic reviews and meta-analyses, including multicenter prospective randomized clinical trials [10]. The studies corresponding to this criterion have not been found in the Russian literature. In the course of the analysis of foreign literature, 9 systematic reviews and meta-analyses were found on the comparison of various surgical treatment options for injuries of the lower thoracic and lumbar spine [11–19].

Five reviews [11–15] provided comparative analysis of anterior and posterior surgical interventions, and four reviews [16–19] – of posterior and combined ones. What calls attention to itself when analyzing the articles included in these reviews, is the high heterogeneity within the compared groups. For example, one review includes studies in which posterior decompression was performed as a repositioning one; the others contain open decompression options. However, in most cases, both techniques are used, depending on the presence and severity of spinal cord injury and the extent of traumatic stenosis. There is no clear indication of the decompression type at all in a number of papers. There is no differentiation according to the type and extent of fixation, the presence and type of fusion. In the studies of the 90s of the last century, the old generation of spinal instrumentation was used for fixation. Meanwhile, the clinical, intraoperative, and spondylometric surgical results are given for the group as a whole. Likewise, in these reviews, the situation is with groups of anterior and combined surgical treatment options. In our opinion, combining such published papers into groups of comparisons as part of a systematic review and meta-analysis does not provide convincing conclusions. Additionally, we did not find systematic reviews comparing simultaneously anterior, posterior, and combined surgical treatment options. Thus, this was the reason the presented study was planned.

The objective was to analyze and compare the clinical efficacy of various technical options for surgical treatment of patients with injuries to the lower thoracic and lumbar spine.

Material and Methods

Search and selection of published materials. To conduct a systematic review, two authors independently searched the literature in the main medical databases such as PubMed, Medline, and The Cochrane Database of Systematic Reviews, using keywords and logistics operators. The search was augmented by the "similar articles" sections and reference lists of the most appropriate papers.

Inclusion criteria:

– articles published between 2001 and 2022;

– patients over the age of 18;

– injury site: lower thoracic and lumbar spine;

– procedures performed in acute and early post-traumatic periods;

– comparative studies of various technical options for surgical treatment;

– the presence of a clear description of the decompression procedure and the technical option of the surgical intervention, including bisegmental fusion;

– the availability of information on the following criteria of the received treatment outcomes:

• the course of neurological status on the Frankel Scale;

• spondylometric data (bisegmental angle of kyphotic deformity calculated by the Cobb method);

• frequency and pattern of complications;

• the possibility of quantitative mathematical analysis of the specified results;

– data availability on the extent of fixation;

– at least 12 months of follow-up;

– articles in English.

Exclusion criteria:

– a multi-level spinal injury;

– studies including less than 10 observations;

– vertebral fractures that are pathological;

– biomechanical studies, the author's techniques;

– procedures utilizing percutaneous and video-endoscopy devices;

– vertebroplasty of the injured segments;

– lack of clear descriptive data on the technical option of the decompression and stabilization procedure in the article.

At the first stage of the search, 5,056 articles on the subject were discovered. Next, we analyzed the titles of papers and excluded duplicate and inappropriate 3,305 publications. During the second stage, composed of the analysis of the abstracts, we excluded 1,626 articles that did not meet the above inclusion-exclusion criteria. In the third stage, full-text editions of articles were studied, as a result of which 68 more articles were excluded. Therefore, 57 published papers were included in the systematic review [20–76].

Various classifications (Magerl (1992), Denis (1976), AO Spine TLICS) were used by the authors of the selected articles to systematize the types of spinal injuries. As a result, in our study, we did not identify the types of injuries in the inclusion criteria. Nonetheless, all the articles included in the review referred to unstable injuries of the lower thoracic and lumbar spine, regardless of the severity of vertebrogenic and neurologic impairment. All the authors provided their patients with indications for decompression and stabilization surgeries with metal fixation of injured SMS.

Analysis of selected articles

The systematization of technical options for surgical treatment of patients with spinal cord injuries of the lower thoracic and lumbar spine was based on approaches and techniques for performing dural sac decompression. Therefore, when studying the selected 57 articles, 5 options of surgeries were highlighted.

Group 1: TPF and a repositioning (closed) posterior decompression. This type of surgical intervention is found in 17 publications: 8 comparative and 9 descriptive researches. The total number of observations is 580 (from 12 to 67 in one article), with an average patients age of 40.5 years at the time of surgery. In six publications, TPF was followed by posterior fusion; in 11 publications posterior fusion was not performed.

Group 2: TPF and posterior open decompression options. This type of surgery is found in 13 articles: 7 comparative and 6 descriptive researches. The total number of observations was 336 (from 14 to 53 in one article), with an average age of 35.5 at the time of surgery. In four publications, TPF was followed by posterior fusion; in nine others posterior fusion was not performed.

Group 3: anterior decompression and anterior fusion. This type of surgery is found in 15 articles: 11 comparative and 4 descriptive researches. The total number of observations was 599 (from 13 to 120 in one article), with an average age of 39.4 at the time of surgery. According to the reviewed studies, patients underwent subtotal corpectomy and bisegmental fusion. The articles in which monosegmental fusion was used are not included in the analysis. During surgery on the L2 vertebral bodies and below, the authors prefer retroperitoneal approaches, on the T12, L1 ones – transdiaphragmatic approaches, and on the T12 one and above – transpleural ones. In nine articles, cages with autologous bone tissue were used as body–substituting materials in patients; an autograft alone was applied in patients in three articles, and either a cage or an autograft was used in patients described in three papers. In all papers, spinal fusion was followed by bisegmental anterior fixation: fixation with a plate – in six papers; rod fixation – in six papers; either with a plate or rods – in three papers.

Group 4: TPF, one-stage circumferential decompression and interbody fusion through a posterolateral approach. This type of surgery is found in nine articles: 3 comparative and 6 descriptive researches. The total number of observations was 215 (from 12 to 47 in one article), with an average age of 42.6 at the time of the procedure. Cages filled with autogenous bone were used in all the studies to reconstruct the central column of the injured SMS. The authors indicate that this procedure is preferable in the treatment of thoracic injuries.

Group 5: decompression and fusion through combined approaches. This type of surgery is found in 11 articles: 6 comparative and 5 descriptive researches. The total number of observations was 408 (from 14 to 92 in one article), with an average age of 39.2 at the time of the procedure. In two papers, the first stage of the procedure consisted of anterior decompression and bisegmental fusion, and the second stage was bisegmental TPF. In nine studies, the first stage included posterior fixation: bisegmental four-screw TPF – in seven papers, eight-screw TPF – in two papers. In three studies, posterior fixation was combined with a repositioning decompression by ligamentotaxis; in the other three researchers, posterior decompression was performed with open options; and in the remaining three studies, posterior decompression was not performed. All articles that formed Group 5 described the performance of a bisegmental anterior fusion during the anterior stage after subtotal corporectomy. Interbody cages filled with autogenous bone were used to replace the ventral column in all studies. In seven papers, both stages were performed with one anaesthetic support; in four, the second stage was postponed (in the period from 7 to 21 days).

For comparative analysis, the following indicators were selected from the articles: the rate of neurologic function recovery; improvement of spondylometric characteristics in injured SMS; the surgery duration; the blood loss volume; and the frequency of complications.

Posttraumatic neurologic impairment before and after surgery (for a period of at least 12 months) in all selected papers was defined according to the Frankel Scale. For each article, we determined the average score on the Frankel Scale according to the technique proposed by Hitchon et al. [54]. A score was given to each category: category A – 1 point; category B – 2 points; C – 3 points; D – 4 points; and E – 5 points. The sum of the points divided by the total number of observations was the average score.

The review contains only those articles in which there is a clear definition of the measuring technique of the angular parameters of injured SMS, namely in a bisegmental manner by the Cobb method. There was no attempt to differentiate articles by the type of fracture. Thus, papers concerning all types of fractures are included in the review. Regarding the fixation extension, the vast majority of analyzed articles concern bisegmental fixation (four-screw TPF or six-screw TPF with placement of screws in a broken vertebra); these articles were included in the analysis. The exception was five papers from Group 4, where an eight-screw TPF was performed since in this particular group they were in the majority. If one of the comparison groups met the inclusion criteria, then only it was included in the review, as, for example, in the study by Hitchon et al. [54] or Xiong et al. [68].

Table 1 shows the general characteristics of the articles included in the systematic review.

Statistical analysis

Firstly, descriptive statistics was used to describe each of the parameters studied in each group. For pairwise comparisons between groups according to above mentioned parameters, the Kruskal – Wallis test was used for several independent samples, based on the initial determination of the normality of data distribution in groups. The Wilcoxon test was used for two dependent samples to determine the differences between the parameters before and after the operation. Differences were considered statistically significant at $p < 0.05$. We used Statistica version 10.0 (StatSoft Inc, USA).

Results

The degree of recovery of spinal cord function

This part of the analysis was devoted only to data from articles that examined the treatment results of patients with spinal cord injury (Table 2). Quantitative information on neurological status before and after surgery, suitable for statistical analysis, were provided in 12 papers in group 1; 11 papers in group 2; 11 papers in group 3; 7 papers in group 4; and 7 papers in group 5.

The average score (M) and limiting indicators (min; max) of the neurological status on the Frankel Scale for each of the groups before and after surgery, as well as the degree of recovery of neurological function, are given in Table 3 and Fig. 1.

Statistical analysis using the Kruskal – Wallis test to compare several independent groups revealed that the level of preoperative neurologic impairment did not differ significantly in all five groups ($p > 0.05$). The Wilcoxon test for dependent samples was used to identify the difference between the extent of neurologic impairment before surgery and at the final follow-up based on the normality of the distribution of data in groups. The latter revealed statistical differences between the neurological status before and after surgery in all groups ($p > 0.05$). The degree of neurological function recovery was the greatest in groups 2 and 3 (by 1 point); the lowest was in group 1 (by 0.71 points). Nevertheless, these differences were statistically insignificant in all compared pairs ($p < 0.05$; Table 4).

Analysis of spondylometric treatment results

Spondylometric parameters quantitatively appropriate for statistical analysis, such as the extent of kyphotic deformity, bisegmentarily measured by the Cobb method before surgery, after surgery, and at the last follow-up, are described in ten papers in group 1; in eight papers in group 2; in eight papers in group 3; in six papers in group 4, and in nine papers in group 5.

The average score (M) and limiting indicators (min; max) of the kyphotic deformity angle before and after surgery, correction of kyphotic deformity, deformity angle at the final follow-up, and the amount loss of deformity correction are presented in Table 5 and in Fig. 2.

Depending on the kyphotic deformity angle before the surgery, all groups were comparable to each other (the Kruskal–Wallis test for all comparing pairs, $p > 0.05$). The kyphotic deformity angle before and after surgery significantly differed in all groups (the Wilcoxon test $p < 0.05$), which signifies sufficient correction in all groups. Nevertheless, the pairwise analysis between the groups did not find statistically significant differences in the extent of correction of posttraumatic deformity ($p > 0.05$; Table 6).

The amount of deformity correction loss was defined by the difference between the deformity angle at the final follow-up and immediately after the surgery. Statistical analysis using the Kruskal – Wallis test showed that in a pairwise comparison, groups 4 and 5 had statistically significant differences compared with groups 1 and 2 ($p < 0.05$), and when compared with each other and group 3, the results were comparable ($p > 0.05$). While comparing all other groups, there were no such differences ($p > 0.05$; Table 7).

Surgery duration

The surgery duration is reported in nine papers in group 1, in ten papers in group 2, in fourteen papers in group 3, in eight papers in group 4, and in eight papers in group 5. Fig. 3 demonstrates the average surgical duration in the groups.

The statistically significant differences found are shown in Table 8.

Therefore, the total duration of the posterior decompression options was the shortest without a statistically significant difference between them but significantly less than in groups 3, 4, and 5. The longest surgery duration was in the combined approach group, with no statistically significant difference with group 3. However, when compared with group 4, significant differences were found. Probably, the ventral stage is the longest one in the surgery.

The volume of intraoperative blood loss

The intraoperative blood loss volume was reported in eight papers in group 1, in eight papers in group 2, in thirteen papers in group 3, in eight papers in group 4, and in eight papers in group 5. The average blood loss volume is shown in Fig. 4.

Table 9 illustrates the statistically significant differences found.

In this regard, the lowest blood loss volume is found in posterior decompression options without a statistically significant difference between them. The greatest blood loss volume was revealed by the group of posterolateral one-stage circumferential decompression. Groups 3, 4 and 5 have no significant differences among themselves.

The frequency and pattern of complications

Data on the frequency and pattern of complications are described in fifteen papers in group 1, in twelve papers in group 2, in fifteen papers in group 3, in eight papers in group 4, and in eleven papers in group 5. The frequency of complications is illustrated in Fig. 5.

Table 10 illustrates the statistically significant differences found.

In this regard, surgeries with the use of the posterior approach statistically significantly had a lower percentage of complications than procedures with the implementation of the anterior stage (groups 3 and 5).

The pattern of complications is given in Table 11.

According to the data of the comparison, the most common complications during posterior decompression (groups 1 and 2) are infectious, including wound infections and urinary tract infections. Pulmonary complications (collapse of the lung lobe, pneumonia, hemo- and/or hydrothorax, pneumothorax) are most common during the anterior stage of surgery (groups 3 and 5), often necessitating surgical drainage measures. The removal of an autograft for the formation of an anterior bone block is often complicated by a complex regional pain syndrome. The third place went to the post-thoracotomy pain syndrome. It is characterized by chronic pain syndrome in the approach area, intercostal neuralgia, anesthesia of the anterior abdomen wall, and weakness of the muscles of the anterior abdominal wall, including the hernia formation.

Table 1
Publications included in the systematic review

Authors	Number of observations, n	Frankel scale (with modification by Hitchon et al.)			The amount of kyphotic deformity, degree					Surgery duration, min	Loss of blood, ml	Compli-cations, n
		Before surgery	After surgery	Recovery	Before surgery	After surgery	Correction	Follow-up	Loss of correction			
Repositioning (closed) posterior decompression												
Prabhakar et al. [20]	20	1.0	2.3	1.3	34.0	3.0	31.0	9.0	6.0	–	–	4
Moon et al. [21]	17	4.5	5.0	0.5	33.0	2.0	31.0	3.0	1.0	–	–	0
Zhang et al. [22]	36	3.1	4.2	1.1	25.9	6.9	19.0	7.9	1.0	119.2	322.2	0
Korovessis et al. [23]	20	4.1	4.5	0.4	13.0	6.7	6.3	11.8	5.1	100.0	850.0	8
Mohanty et al. [24]	66	3.00	3.80	0.80	17.45	–	–	6.43	–	–	–	–
Aono et al. [25]	27	4.2	4.7	0.5	13.0	1.0	12.0	3.3	2.3	101.0	142.0	0
Yang et al. [26]	64	4.1	4.6	0.5	18.9	0.5	18.4	3.3	2.8	–	–	0
Mahar et al. [27]	12	–	–	–	9.2	-6.2	15.4	-0.8	5.4	–	–	1
Yang et al. [28]	22	3.40	4.60	1.20	14.85	8.76	6.09	8.50	0.26	93.7	188.6	0
Guven et al. [29]	36	–	–	–	20.90	6.85	14.05	10.10	3.25	130.0	436.0	0
Liao et al. [30]	27	4.8	5.0	0.2	20.9	6.0	14.9	9.9	3.9	141.0	126.2	1
Zhao et al., 2015 [31]	67	–	–	–	20.145	7.545	12.600	11.615	4.070	104.38	223.97	2
Martin-Somoza et al. [32]	54	–	–	–	14.98	7.50	7.48	12.11	4.61	191.85	–	4
Gajjar et al. [33]	32	2.40	3.30	0.90	16.00	4.20	11.80	4.55	0.35	–	–	4
Altay et al. [34]	32	4.9	5.0	0.1	20.7	7.8	12.9	13.0	5.2	–	–	4
Lin et al. [35]	20	–	–	–	22.3	5.6	16.7	10.3	4.7	142.0	101.7	0
Jaiswal et al. [36]	28	2.96	4.17	1.21	–	–	–	–	–	–	–	–
Posterior open decompression options												
Wang et al. [37]	23	3.5	4.3	0.8	18.5	1.0	17.7	9.8	8.8	110.0	357.0	3
Kuang et al. [38]	21	3.7	4.7	1.0	17.3	–	–	9.2	–	150.0	400.0	1
Park et al. [39]	27	3.5	4.6	1.1	15.8	6.5	9.3	8.9	2.4	180.9	–	0
Kumar et al. [40]	22	2.20	3.80	1.60	17.45	9.82	7.63	11.41	1.60	142.0	214.0	0
Deng et al. [41]	53	2.4	3.6	1.2	17.2	–	–	8.4	–	93.0	452.0	3
Mittal et al. [42]	14	2.00	2.60	0.60	16.29	6.93	9.36	9.23	3.58	192.6	478.6	2
Hegde et al. [43]	30	–	–	1.5	19.9	9.3	10.6	10.9	1.6	150.0	–	11
Khare et al. [44]	25	2.28	3.40	1.12	20.00	7.80	12.20	8.90	1.10	–	–	13
Xiong et al. [45	26	–	–	–	15.0	3.4	11.6	8.0	4.6	115.0	50.0	0
Kong et al. [46]	24	2.60	3.45	0.85	30.00	6.10	23.90	–	–	–	–	1
Zhang et al. [47]	29	3.1	4.0	0.9	22.3	5.1	17.2	10.3	5.5	151.0	437.8	0
Shin et al. [48]	24	3.5	4.5	1.0	15.8	6.5	9.3	8.9	2.4	180.9	289.2	0
Jaiswal et al. [36]	18	2.7	4.1	1.4	–	–	–	–	–	–	–	–
Anterior decompression												
Shin et al. [48]	22	3.5	4.3	0.8	18.3	11.9	6.4	21.8	9.9	293.9	1566.6	3
Kang et al. [49]	43	–	–	–	25.15	1.90	23.25	4.18	2.28	331.7	2655.3	15

End of the Table 1

Authors	Number of observations, n	Frankel scale (with modification by Hitchon et al.)			The amount of kyphotic deformity. degree					Surgery duration, min	Loss of blood, ml	Compli-cations, n
		Before surgery	After surgery	Recovery	Before surgery	After surgery	Correction	Follow-up	Loss of correction			
Liang et al. [50]	120	2.60	3.76	1.16	19.20	2.20	17.00	2.50	0.30	122.8	734.5	2
Wang et al. [51]	72	4.00	4.70	0.70	15.38	1.62	13.76	1.60	0	194.4	973.9	19
Pan et al. [52]	21	–	–	–	25.0	8.0	17.0	10.0	2.0	166.2	500.0	2
Stancić et al [53]	13	3.3	4.8	1.5	–	–	–	–	–	250.0	1362.0	3
Hitchon et al. [54]	38	3.7	4.2	0.5	11.9	2.0	9.9	4.5	2.5	415.0	–	2
Sasso et al. [55]	40	3.0	4.3	1.3	22.7	7.4	15.3	9.2	1.8	–	–	6
Wood et al. [56]	20	–	–	–	10.50	4.75	5.75	11.00	6.25	233.0	784.0	3
Wang et al. [37]	22	3.5	4.4	0.9	15.9	0.8	15.1	8.9	8.1	198.0	570.8	1
Dai et al. [57]	65	4.4	4.9	0.5	22.0	2.0	20.0	4.0	2.0	168.3	371.5	32
Lin et al. [58]	32	2.60	3.90	1.30	24.11	5.23	18.88	6.23	1.00	172.5	811.6	45
Xu et al. [59]	48	3.95	4.8	0.85	21.4	–	–	–	–	224.0	950.0	0
Zahra et al. [60]	22	–	–	–	15.0	9.6	5.4	11.5	1.9	185.0	1445.0	6
Sharma et al. [61]	21	2.8	3.9	1.1	23.0	4.0	19.0	7.0	3.0	298.0	548.0	7
One-stage circumferential decompression through posterior approach (360 fusion)												
Lin et al. [58]	32	2.70	4.00	1.30	23.62	5.13	18.49	6.14	1.00	157.3	720.0	8
Haiyun et al. [62]	37	3.40	4.40	1.00	25.77	3.70	22.05	4.49	0.79	157.0	1086.0	2
Liu et al. [63]	20	2.25	2.90	0.65	26.15	5.39	20.76	5.90	0.51	195.0	2800.0	1
Sasani et al. [64]	14	4.0	4.4	0.4	24.6	15.5	9.1	17.1	1.6	187.8	596.4	1
Jo et al. [65]	16	3.75	4.18	0.43	18.50	-10.30	28.80	-9.20	1.10	255.0	1073.0	1
Gao et al. [66]	20	3.15	4.80	1.65	30.20	–	–	6.50	–	–	–	0
Zheng et al. [67]	12	–	–	–	39.8	4.8	35.0	4.9	0.1	214.0	1856.0	1
Xiong et al. [68]	47	3.36	4.40	1.04	26.10	7.20	18.90	10.15	2.95	172.5	390.0	-
Hofstetter et al. [69]	17	–	–	–	16.7	10.9	5.8	11.8	0.9	289.0	1041.0	4
Decompression through combined approach												
Prabhakar et al. [20]	20	1.00	2.75	1.75	34.00	8.00	26.00	8.00	0	–	–	12
Korovessis et al. [23]	20	4.20	4.65	0.45	20.30	12.00	8.30	14.30	2.30	245.0	1500.0	21
Zheng et al. [67]	14	–	–	–	34.7	2.8	31.9	2.8	0	284.0	2453.0	6
Payer et al. [70]	20	3.25	4.15	0.90	16.00	-2.00	18.00	1.00	3.00	331.0	1350.0	4
Xia et al. [71]	34	2.60	3.35	0.75	–	–	–	–	–	230.0	1200.0	6
Machino et al. [72]	92	3.60	4.56	0.96	12.20	-3.50	15.70	-0.80	2.70	255.6	985.4	6
Schnake et al. [73]	80	4.16	4.70	0.54	8.90	-0.20	9.10	2.40	2.60	–	–	37
Wang et al. [37]	21	3.47	4.30	0.83	18.10	0.90	17.20	4.30	3.40	248.5	780.3	2
Todeschi et al. [74]	66	–	–	–	14.5	9.1	5.4	8.7	0.4	250.0	180.0	9
Grobost et al. [75]	29	–	–	–	12.9	-2.7	15.6	1.7	4.4	–	–	3
Theologis et al. [76]	12	–	–	–	12.0	-10.0	22.0	-7	3.0	288.7	988.0	8

Table 2
Quantitative distribution of publications in each group according to the pattern of injury, n

Group	SCI (category from D to A)	SCI and isolated spine injury (category from E to A)	Isolated spinal injury only (category E)
Posterior repositioning decompression	4	9	4
Open decompression options	8	5	0
Anterior decompression	3	11	1
Posterolateral one-stage circumferential decompression	5	4	0
Decompression through combined approaches	2	9	0

SCI — spinal cord injury.

Discussion

In a meta-analysis by Ren et al. [11], including 15 randomized clinical trials (RCTs) comparing anterior and posterior decompression in spinal cord injury, the degree of neurologic function recovery was greater in the anterior decompression group ($p < 0.05$), and the surgery duration, the intraoperative blood loss volume, and the length of hospital stay were significantly less in the posterior decompression group ($p < 0.05$).

In the systematic review devoted to the comparative analysis of anterior and posterior surgical approaches, Figueiredo et al. [12] proved that the degree of neurologic functional recovery according to the ASIA scale is greater in the anterior decompression group. The surgery duration and blood loss volume are lower in the posterior decompression group. Nonetheless, no statistical analysis has been performed in this study.

In 2020, Tan et al. [13] analyzed the treatment results of burst fractures of the thoracolumbar junction using anterior and posterior surgeries. The analysis included 6 studies (2 RCTs, a prospective non-randomized study and 3 retrospective cohort studies). The authors showed a longer surgery duration and intraoperative blood loss when using anterior approaches compared to posterior ones ($p < 0.001$). There was no statistically significant difference in the length of hospital stay and deformity correction. The

Table 3
Neurological status according to the Frankel scale in the comparison groups, M (min; max), points

Group	Neurological status before a surgery	Neurological status at final follow-up	Degree of neurological improvement
1	3.54 (1.00; 4.90)	4.25 (2.30; 5.00)	0.71 (0.10; 1.30)
2	2.90 (2.00; 3.70)	3.90 (2.60; 4.70)	1.00 (0.60; 1.60)
3	3.40 (2.60; 4.40)	4.30 (3.76; 4.90)	0.90 (0.50; 1.50)
4	3.20 (2.25; 4.00)	4.20 (2.90; 4.80)	1.00 (0.40; 1.65)
5	3.50 (1.00; 4.20)	4.30 (2.75; 4.70)	0.80 (0.45; 1.75)

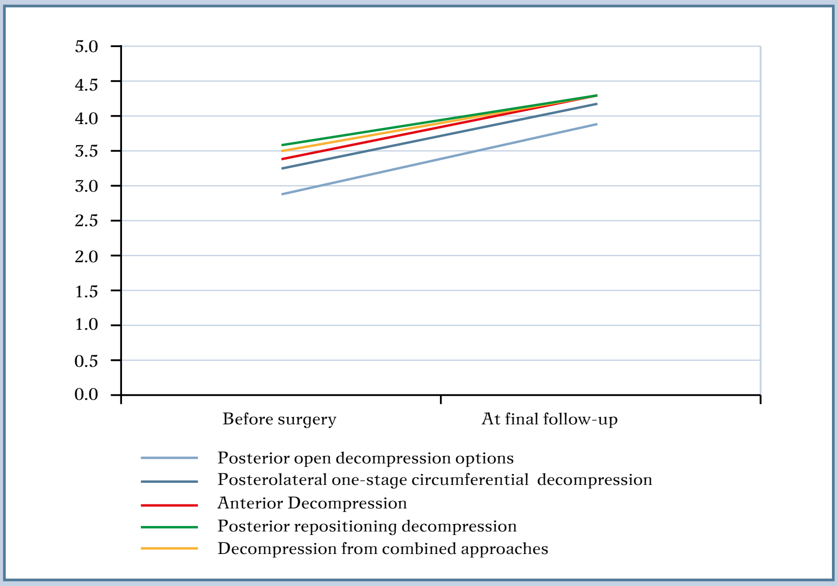

Fig. 1
Dynamics of neurological status in comparison groups

Table 4

Pairwise comparative analysis of the degree of neurological recovery according to the Frankel scale in the comparison groups

Groups	1	2	3	4	5
1		p = 0.0841	p = 0.1633	p = 0.4457	p = 0.5253
2			p = 0.5319	p = 0.5553	p = 0.1233
3				p = 0.6828	p = 0.5255
4					p = 0.8480
5					

analysis of the degree of neurologic function recovery has not been performed in this study.

A team of authors headed by Zhu [14] in a paper comparing anterior and posterior options of surgical treatment, which included 12 studies (3 RCTs and 9 clinical controlled trials), showed that the differences between the groups were only in the surgery duration and in the blood loss volume in favor of posterior ones ($p < 0.05$). The extent of correction and loss of correction of kyphotic deformity, as well as the degree of neurologic function recovery and the frequency of complications, were comparable between the groups ($p > 0.05$).

A meta-analysis by Xu et al. [15] is devoted to the comparison of anterior surgeries and one-stage posterior ones, which included four RCTs and three controlled clinical trials. 179 patients who underwent the surgery with the use of anterior approaches and 152 patients who underwent the surgery with the use of posterior approaches were included in the analysis. The authors reported no significant difference between the groups in the loss of deformity correction ($p = 0.84$), the degree of neurological improvement ($p = 0.38$), the frequency of complications ($p = 0.13$), as well as in functional outcomes ($p = 0.80$). An anterior approach was associated with a longer surgery duration ($p = 0.003$) and greater blood loss ($p = 0.03$).

In a systematic review by Tan et al. [16], which includes five retrospective cohort studies (level 3 evidence) devoted to a comparative analysis of combined and posterior approaches in the surgical treatment of patients with injuries of the lower thoracic and lumbar spine, there were no significant differences between the two approaches regarding the loss of correction of kyphotic deformity ($p = 0.936$). The surgery duration, blood loss volume, and length of hospital stay were greater in the combined group in one study and equivalent between the groups in another. Additionally, there was no significant difference in functional outcomes, the intensity of the VAS pain syndrome, and the recovery time back to work between the two groups ($p > 0.05$).

In a systematic review and meta-analysis by Smits et al. [17], which included 2 RCTs and one retrospective cohort study, the authors concluded that the combined group had no statistically significant differences compared to the group of posterior approaches to preserve a large correction of kyphosis ($p = 0.22$). Neurological improvement and functional outcome did not differ in both groups. The surgery duration, blood loss volume, and hospital stay were significantly lower in the posterior surgery group ($p < 0.05$).

Oprel et al. [18] performed a systematic review with meta-analysis that includ-

Table 5

Spondylometric results of treatment, M (min; max), degree

Surgery option	Kyphotic deformity angle before a surgery	Kyphotic deformity angle after a surgery	The amount of kyphotic deformity correction	Angle of kyphotic deformity at final follow-up	The amount of loss of kyphotic deformity correction
Posterior repositioning decompression	19.86 (9.20; 34.00)	4.30 (-6.20; 8.76)	15.56 (6.00; 31.00)	8.10 (-0.80; 13.00)	3.80 (0.26; 6.00)
Open decompression options	19.35 (15.00; 22.30)	5.65 (1.00; 9.82)	13.70 (9.30; 23.90)	9.49 (8.00; 11.41)	3.84 (1.10; 8.80)
Anterior decompression	18.50 (10.50; 25.15)	4.30 (0.80; 11.90)	14.20 (5.40; 23.25)	7.40 (1.60; 21.80)	3.10 (0.00; 9.90)
Posterolateral one-stage circumferential decompression	25.00 (16.70; 39.80)	5.38 (-10.30; 15.50)	19.62 (5.80; 28.80)	6.95 (-9.20; 17.10)	1.57 (0.10; 2.95)
Decompression through combined approaches	15.00 (8.90; 34.00)	0.68 (-10.00; 12.00)	14.32 (5.40; 31.90)	2.73 (-7.00; 14.30)	2.05 (0.00; 4.40)

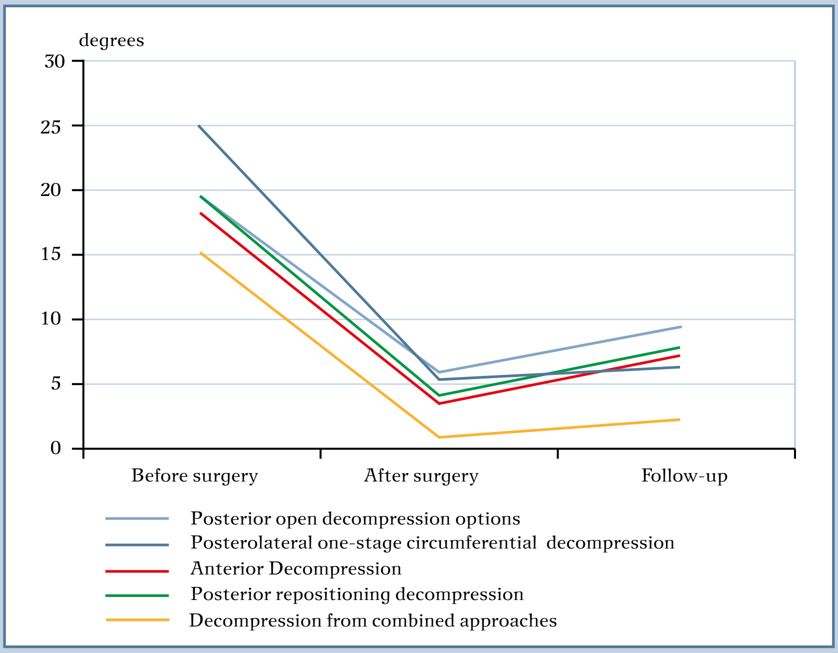

Fig. 2
Average angle of kyphotic deformity in the studied groups

Table 6
Pairwise analysis of the amount of kyphotic deformity correction between groups

Groups	1	2	3	4	5
1		p = 0.2476	p = 0.4237	p = 0.5873	p = 0.5134
2			p = 0.7525	p = 0.4381	p = 0.3601
3				p = 0.1967	p = 0.2288
4					p = 0.5165
5					

Table 7
Pairwise analysis of the amount of loss of kyphotic deformity correction between groups

Groups	1	2	3	4	5
1		p = 0.9222	p = 0.7223	p = 0.0067	p = 0.0410
2			p = 0.7282	p = 0.0122	p = 0.1848
3				p = 0.0528	p = 0.4985
4					p = 0.3449
5					

ed five studies comparing combined and posterior surgical options with a total of 755 patients. Correction of kyphotic deformity was higher in the combined surgery group ($p < 0.00001$). The loss of correction of kyphotic deformity ($p = 0.70$) and the degree of postoperative pain syndrome ($p = 0.26$) did not differ between the groups. The surgery duration, the blood loss volume, and the length of hospital stay were significantly greater in the combined group ($p < 0.00001$; $p = 0.02$; $p = 0.0001$, respectively). The functional outcome of surgical treatment did not differ significantly between the groups ($p > 0.05$). There were no differences in the frequency of complications ($p > 0.05$).

In a recent systematic review and meta-analysis by Hughes et al. [19], which included four RCTs involving 145 randomized participants, the authors performed a comparative analysis of combined and posterior surgical treatment options. There was no significant difference in the degree of correction of posttraumatic deformity ($p = 0.39$), functional outcomes ($p > 0.05$), and the number of postoperative complications between the two approaches ($p = 0.49$). The performance of posterior procedures was associated with less blood loss volume ($p < 0.001$) and surgery duration ($p < 0.001$). The combined approach had a lower degree of loss of correction of kyphotic deformity at the final follow-up ($p = 0.001$).

Therefore, from 2010 to 2021, a sufficient number of systematic reviews and meta-analyses have been published in the foreign literature, which indicates the relevance of the problem of choosing a surgical treatment option for injury of the transitional thoracolumbar spine. Nevertheless, comparative studies on this issue with a high level of evidence, which should be included in these reviews, are published much less frequently. This has resulted in the fact that most of the above systematic reviews include the same studies in various combinations. In foreign literature, the term “posterior decompression” has an indefinite interpretation. A number of authors use this term to mean ligamentotaxis; the others mean open posterior decompression; and some mean circumferential decompression from the posterior approach with anterior fusion. Furthermore, a detailed analysis of the review papers reveals that the authors include studies on post-traumatic deformities and pathological fractures associated with osteo-

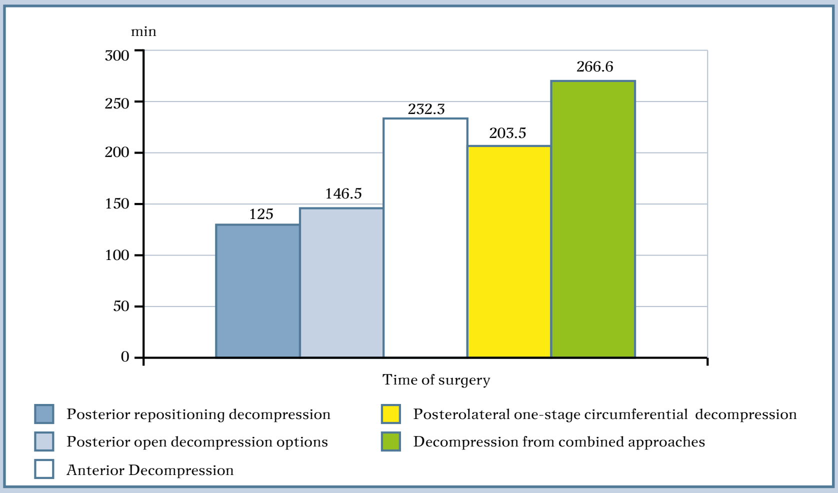

Fig. 3
Average time of surgery in the study groups

Table 8
Pairwise analysis of surgery duration between groups

Groups	1	2	3	4	5
1		p = 0.1109	p = 0.0005	p = 0.0021	p = 0.0005
2			p = 0.0019	p = 0.0076	p = 0.0004
3				p = 0.3934	p = 0.1421
4					p = 0.0274
5					

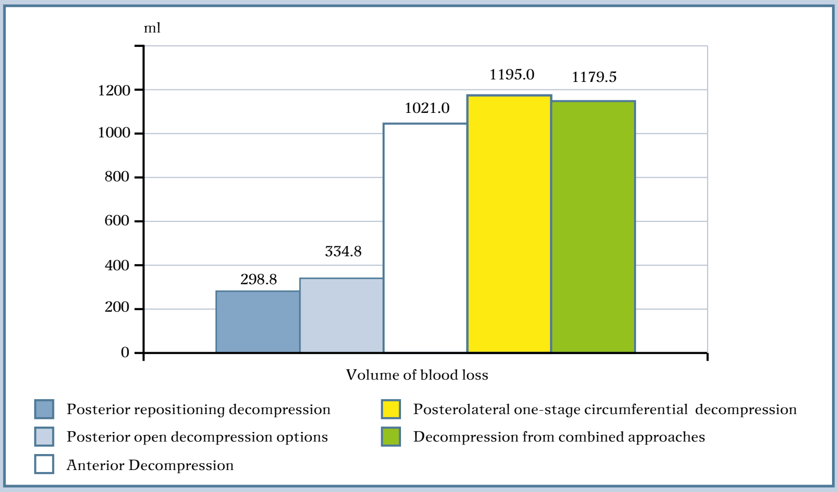

Fig. 4
Average volume of blood loss in study groups

porosis in the review [14], probably trying to overcome the problem of scarcity of data. Therefore, more than half of the reviews include studies from the 90s of the last century.

In this regard, despite the sufficient amount of literature available today, the methodology of its analysis permits making recommendations of a very general and inconclusive nature. To form a domestic recommendation base for the surgical treatment of injuries to the lower thoracic and lumbar spine, it is essential to perform multicenter randomized prospective clinical trials on this issue in our country.

Conclusion

1. There are no differences in the dynamics of neurologic function recovery in patients with spinal cord injury in the lower thoracic or lumbar spine with the use of five different surgical options.
2. There are no differences in the quality of correction of kyphotic deformity of injured SMS between all the studied groups.
3. Statistically significant lower loss of deformity correction was found in patients who underwent circumferential one-stage decompression from the posterolateral approach and combined approaches. Meanwhile, procedures from posterior or anterior isolated approaches for this value have comparable outcomes.
4. Surgeries with decompression of the dural sac from the posterior approaches are characterized by significantly shorter surgery duration than surgeries with decompression from the anterior and combined approaches.
5. The lowest blood loss volume is seen in procedures involving decompression from isolated posterior approaches; the largest blood loss volume is found in the group with posterolateral approach and one-stage circular decompression.
6. Surgeries involving the posterior approach statistically significantly have a lower percentage of complications than procedures involving the anterior stage.

The study had no sponsors. The authors declare that they have no conflict of interest.

Table 9

Pairwise analysis of intraoperative blood loss between groups

Groups	The 1st	The 2nd	The 3rd	The 4th	The 5th
The 1st		p = 0.2936	p = 0.0014	p = 0.0033	p = 0.0063
The 2nd			p = 0.0005	p = 0.0033	p = 0.0087
The 3rd				p = 0.5145	p = 0.3848
The 4th					p = 0.8336
The 5th					

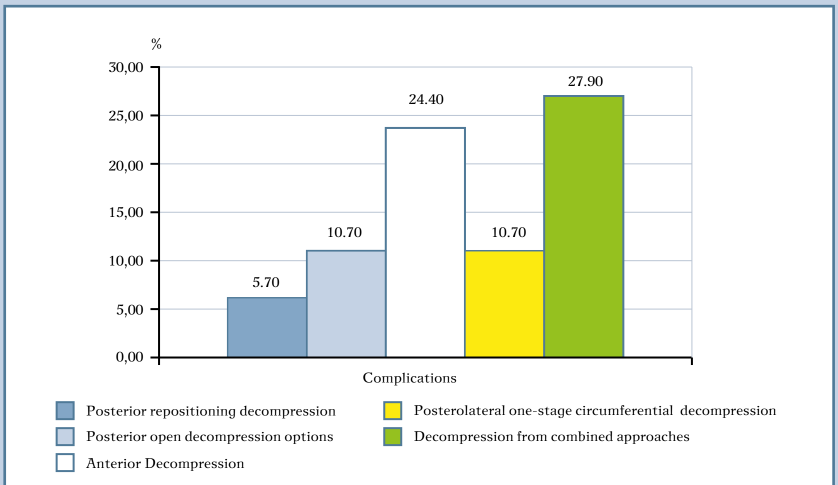

Fig. 5
Complication rate in study groups

Table 10

Pairwise analysis of complication frequency between groups

Groups	The 1st	The 2nd	The 3rd	The 4th	The 5th
The 1st		p = 0.8778	p = 0.0124	p = 0.4415	p = 0.0006
The 2nd			p = 0.0233	p = 0.6341	p = 0.0048
The 3rd				p = 0.0435	p = 0.2397
The 4th					p = 0.0041
The 5th					

Table 11
Pattern of complications in study groups, n

Surgery option	Pain syndrome			Infectious complications			Pulmonary complications	Thrombo-embolic complications	Early destabilization of metal structures	Others	Total, n (%)
	Wound pain	pain at the site of the autograft	Post-thoracotomy syndrome	Suppuration of the wound		urinary tract infection					
				superficial	deep						
Posterior repositioning decompression	5	1	–	5	2	1	2	1	–	8 – bedsores, 2 – screw malposition, 1 – mental disorders	28 (5.7)
Posterior open decompression	–	–	–	4	2	10	2	–	3	9 – bedsores, 1 – lethal outcome, 3 – screw malposition	34 (10.7)
Anterior decompression	–	49	6	3	1	7	54	2	5	1 – screw malposition, 1 – chylothorax, 1 – ketoacidosis, 1 – pseudoarthrosis, 14 – intestinal obstruction, 1 – hematuria	146 (24.4)
Posterolateral one-stage circumferential decompression	1	–	–	2	–	–	2	–	3	5 – intestinal obstruction, 2 – liquorrhea, 1 – neurological deterioration, 2 – epidural hematoma	18 (10.7)
Decompression through combined approaches	3	4	18	23	4	4	35	5	2	2 – screw malposition, 1 – bedsore, 2 – epidural hematoma, 2 – intestinal obstruction, 1 – neurological deterioration, 1 – blood transfusion, 2 – cardiac complications, 1 – subsplenic hematoma, 3 – gastrointestinal bleeding, 1 – kidney failure	114 (27.9)

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