COMPLICATIONS OF THE TREATMENT OF POST-TRAUMATIC DEFORMITIES OF THE THORACIC AND LUMBAR SPINE USING STAGED SURGICAL INTERVENTIONS

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Objective. To analyze the results of surgical treatment of post-traumatic deformities of the thoracic and lumbar spine using staged surgical interventions from the point of view of surgical safety, and to study the structure, frequency and nature of intra- and postoperative complications and intraoperative blood loss.

Material and Methods. A retrospective analysis of data of 212 patients for 2015—2018 was performed. Inclusion criteria were: age over 18 years, staged surgical interventions including anterior spinal fusion and posterior internal fixation performed in one surgical session for post-traumatic deformities of the thoracic and lumbar spine. Patient demographic data and surgical intervention protocols were studied taking into account surgical approaches, duration of operations and blood loss. Intraoperative and postoperative complications up to 6 weeks after surgery were taken into account. Intraoperative blood loss was studied both as the absolute volume and as the percentage of circulating blood volume (CBV).

Results. Complications after staged surgical correction of post-traumatic deformities were recorded in 14.2 % of patients, including intraoperative complications in 3.3 % of cases, and postoperative complications in 10.9 %. The most common complications were surgical site infections, usually after posterior approach, and pneumonia. The number of neurological complications was 1.4 %. Complications were more frequent after three-stage surgical interventions than after two-stage ones. The lumbar spine deformity correction was associated with higher complication rate than that in the thoracic spine. Intraoperative blood loss in the study group was 562.2 ± 504.7 ml. The most significant blood loss, over 30 % of the CBV, was noted in 13 (6.1 %) patients. Using of minimally invasive transpedicular fixation during the staged surgical intervention provided the least number of infectious wound complications and the smallest amount of intraoperative blood loss.

Conclusion. Staged surgical intervention for the correction of post-traumatic deformity of the thoracic and lumbar spine is a safe method of surgical treatment.

Key Words: post-traumatic spinal deformities, thoracic and lumbar spine, staged surgical interventions.

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Treating rigid post-traumatic spinal deformities is a more complicated challenge than surgical management of an acute spinal injury. Surgical treatment of this pathology is aimed to correct a post-traumatic deformity and achieve stable fixation for a period required for the formation of spinal fusion.

Spinal osteotomy is widely used for this purpose. Three-column resection osteotomies are a powerful tool to correct fixed multicomponent spinal deformities through a single-stage posterior approach. These methods include grades 3, 4, and 5 of resection according to the classification proposed by Schwab et al. [1]: pedicle subtraction osteotomy (PSO), ventral column resection (VCR), and kyphectomy (VCD), respectively.

Corrective osteotomies are purely posterior surgeries. That is why wide resection of pedicles, a portion of the vertebral body, and the intervertebral disc needs to be performed to ensure full-scale deformity correction. Although these methods demonstrate perfect opportunities for deformity correction, they also have some drawbacks, including high technical complexity, the need to manipulate in close vicinity to the neural structures, high invasiveness causing intra- and postoperative complications, and significant blood loss. Researchers demonstrate that patients who have undergone osteotomies develop more complications than those who have undergone other surgical spinal interventions; more aggressive osteotomies are associated with high complication rate [2–5].

Staged surgical interve ntions that involve anterior and posterior stages and are accompanied (if necessary) with surgical release are considered to be an alternative to the correction of rigid spinal deformities [6]. Formally, this surgical method is more aggressive: it includes operations involving several

anatomical areas. However, in our opinion, staged interventions bear lower risks of complications (especially the neurological ones); and the traumaticity of staged surgery is currently to a great extent reduced by using minimally invasive surgical methods.

The objective of this study was to analyze the results of surgical treatment of post-traumatic deformities of the thoracic and lumbar spine using staged surgical interventions in terms of their surgical safety, as well as to study the structure, frequency and nature of intra- and postoperative complications, and the intraoperative blood loss.

Material and Methods

The study is a retrospective analysis of the data of 212 patients operated on at the Novosibirsk Research Institute of Traumatology and Orthopedics n.a. Ya.L. Tsivyan in 2015–2018. The inclusion criteria were as follows: age over 18 years; staged surgical interventions (anterior spinal fusion and posterior internal fixation) performed during a single surgical session to manage post-traumatic deformities of the thoracic and lumbar spine.

The staged surgical intervention procedure includes the anterior stage, when post-traumatic kyphotic deformity is corrected, and the posterior stage intended for stable fixation of the anterior fusion area for a period necessary for the formation of anterior spinal fusion. If spontaneous posterior fusion immobilizing metal instrumentation had been formed, posterior release surgeries (facetectomy and instrumentation removal) were carried out as a preliminary stage in one surgical session, so these were three-stage surgical interventions. The anterior aspects of vertebral bodies in the thoracic and upper lumbar spine were reached through the thoracic and thoracophrenolumbar approaches, while different modifications of the extraperitoneal approach were used to access the lumbar spine. Two variants of transpedicular fixation were used: the conventional posteromedial approach and the minimally invasive one. Posterior spinal fusion was not used during the surgery. When needed, the anterior stage also involved anterior decompression; the indications for it included the spinal canal size in accordance with the criteria proposed by Hashimoto et al. [7] or clear signs of compression of the neural structures.

The patients' demographic data and surgical intervention protocols were studied taking into account surgical approaches, surgery duration, and blood loss.

Comparative analysis of the major intraoperative and postoperative complications was performed according to the criteria proposed by Schwab et al. [8]. Postoperative complications were defined as those that had developed within six weeks after the surgery [8].

Intraoperative blood loss was studied both as the absolute volume and as a percentage of the circulating blood volume (CBV). The intraoperative blood loss was calculated gravimetrically and by measuring the blood volume aspirated into graduated containers. The following formula was used to calculate the CBV: CBV = patient's body weight × 0.7 [9]. All the data were analyzed using the SPSS 19.0 software (SPSS Inc.). The significance threshold was set to 0.05; the differences were regarded at significance level < 0.05 ($P < 0.05$).

Results

Characteristics of the study group. The group contained 108 (51 %) female and 104 (49 %) male patients; the mean age was 44.1 ± 14.8 years (range, 19–78 years). The period between the injury and the surgery varied between 3 and 240 months (mean duration, 20.6 ± 45.3 months).

Post-traumatic deformities were characterized by the presence of local kyphosis in the thoracic and lumbar spine; the segmental Cobb angle was 20–57° (mean, 29.9° ± 9.6°). In 210 patients, the deformities were classified as rigid (without pathological mobility at the deformity apex). Pathological mobility caused by fusion failure was observed in two patients.

The number of patients with the sequelae of spine and spinal cord injury was 34 (16.0 %). According to the Frankel grade classification, complete neurological impairment (paraplegia) was observed in nine patients, while the remaining 25 patients showed incomplete neurological impairment (Frankel grade C – four patients; Frankel grade D – 21 patients) and were able to move independently.

Thirty (14.1 %) patients underwent corrective interventions for post-traumatic deformities after the previously failed surgeries. Prior surgeries with unsatisfactory results included anterior interventions in eight patients, laminectomies in 11 patients, failed transpedicular fixation in seven patients, and various types of instrumentation fixation to the spinous processes in four patients. A total of 212 patients underwent 485 surgical interventions. Fifty-one (24.1 %) patients underwent additional release stages (i.e., three-stage interventions during a single surgical session). In 110 (51.8 %) patients, the posterior stage was carried out using minimally invasive transpedicular fixation; anterior decompression was performed during anterior interventions in 18 patients.

The mean duration of a surgical session (the total duration of all the stages) was 256 min (130–650 min) in the study group. No deaths were reported.

The rate of intraoperative and postoperative complications. Forty-three complications (including seven intraoperative and 36 postoperative ones) were documented for 34 (16.0 %) patients. In accordance with the criteria of complications proposed by Schwab et al., 28 patients had 33 (13.24 %) major complications.

Major intraoperative complications (according to the criteria proposed by Schwab et al.) were revealed in five (2.3 %) patients (Table 1); postoperative complications were documented for 23 (10.8 %) patients (Table 2).

We can also note the following postoperative complications in our patients (these complications did not meet the abovementioned criteria): four (1.8 %) cases of catheter-induced cystitis,

three (1.4 %) cases of transient psychotic disorders, one (0.4 %) case of toxic hepatitis, one (0.4 %) case of gastrointestinal bleeding because of Mallory–Weiss tear, and one (0.4 %) case of pleural effusion.

Five patients had two major complications. Of those, two patients had two intraoperative complications each, two patients had two postoperative complications each, and one patient had both an intraoperative and a postoperative complication.

Patients older than 60 years did not have intraoperative complications. Such complications were recorded in younger patients. Patients older than 60 years (n = 31) had a sufficiently higher rate of postoperative complications than younger patients (n = 181): 22.5 % and 10.4 %, respectively.

Patients with BMI ⩾25 kg/m^2 did not have any intraoperative complications. At the same time, postoperative complications were recorded in 13 (13.5 %) cases. All intraoperative complications and ten (8.6 %) postoperative ones were observed in patients with BMI <25 kg/m^2.

Thirty-four patients having sequelae of spine and spinal cord injuries had complications in five (14.7 %) cases, including four intraoperative complications in two patients and four postoperative complications in three patients.

Among 30 patients who had earlier undergone surgical interventions, two patients had four intraoperative complications and one patient had one postoperative complication.

In the study group, the rate of intra- and postoperative complications tended to increase with the degree of local kyphosis (Table 3).

Intraoperative blood loss. The mean intraoperative blood loss in the study group was 562.2 ± 504.7 ml. The results of the analysis of the intraoperative blood loss in accordance with the WHO criteria are presented in Figure. The threshold of blood loss > 30 % of the CBV was used for further evaluation of the results of various surgical treatment types as it is the most practically important parameter requiring the adjustment of homeostatic parameters.

Out of 212 patients, 18 patients underwent anterior spinal cord decompression during the anterior stage. In this case, the average blood loss was 1,565 ± 989 ml (between 200 ml and 4,620 ml); the mean CBV loss was 33.7 ± 21.6 %.

Eight patients underwent revision decompression combined with stabilization surgeries on the anterior spine because of the presence of anterior fusion. In this case, the mean blood loss was 1,601 ± 1,458 ml, of these. four patients had the greatest blood loss in the entire study group (2,645 ± 1,445 ml).

Stages of surgical interventions. The number of complications and the blood loss data in patients who had undergone two-stage (161 patients) and three-stage (51 patients) surgical interventions are compared in Table 4.

The patients who had undergone three-stage interventions developed more intraoperative (7.8 % and 1.9 %) and postoperative (19.6 % and 9.9 %) complications. The highest mean blood loss and the blood loss > 50 % of the CBV were recorded in patients after three-stage interventions.

Localization of post-traumatic kyphosis, the types of approaches used during the anterior and posterior stages of surgical interventions. When a post-traumatic deformity was located at the level of the T3–L1 vertebrae, the transthoracic approach was used during the anterior stage of the intervention in 155 patients. Among 56 patients with post-traumatic deformities of the lumbar spine at the L2 level, the thoracophrenolumbar approach was used in 28 cases, and different variants of the retroperitoneal approach (the deformity apex at the L3–L5 level) were used in 29 patients.

There were no intraoperative complications directly related to the certain type of surgical anterior approach in the study group. The postoperative complications related to the anterior approach included two cases of pulmonary atelectasis, one case of pleural effusion, and one case of the thoracic approach site infection. The six cases of plexopathies and neuropathies of the upper extremities mentioned above also referred to complications related to anterior approaches because they resulted from improper patient positioning on an operating table before the anterior intervention.

In general, the number of complications is higher for staged interventions for lumbar deformities than that in case of the thoracic spine (Table 5), and they are accompanied with higher blood loss volume.

Transcutaneous transpedicular fixation was used in 110 (51.8 %) patients during the posterior fixation stage of the surgical intervention. This category of patients did not have surgical site infection ; the number of intraoperative and postoperative complications was lower than that when the conventional open transpedicular fixation was used. The mean blood loss during the posterior stage and the total blood loss during all the stages were lower than those for the open transpedicular fixation (Table 6).

Moreover, surgical site infections associated with posterior approach were more likely to develop in patients with BMI ⩾25 kg/m^2 than in patients with BMI <25 kg/m^2 (eight (6.4 %) cases vs. three (3.4 %) cases). At the same time, the use of minimally invasive transpedicular fixation did not cause surgical site infections in patients with BMI ⩾25 kg/m^2.

Discussion

The objective of surgical treatment of post-traumatic deformities in the thoracic and lumbar spine is to correct deformities and to create conditions for the formation of spinal fusion. Over the past decade, various methods to achieve this objective have been reported in the literature, including various methods of spinal osteotomy and, much less often, anterior corrective interventions and combined anteroposterior interventions [10]. There is no doubt that three-column osteotomies are able to correct severe multicomponent local and mild spinal deformities. Most post-traumatic deformities are known to result from type A injuries (83.5 % according to our data [6]). Much less commonly, they are caused by type B or C injuries or are the sequelae of prior failed surgeries. In our experience, surgical treatment of post-traumatic kyphotic deformities

of the thoracic and lumbar spine is an indication to perform staged surgical interventions. The purpose of correcting spinal osteotomies in the surgery of post-traumatic deformities is to treat a combination of the kyphotic and translation (shift) deformities, as well as the deformity in the cervicothoracic spine (the T2–T4 level), where the use of anterior corrective spinal fusion is technically complicated [11].

Table 1
Intraoperative complications in patients of the study group (according to the criteria proposed by Schwab et al.)

Complication	Number
Cardiac arrest	0
Cerebrospinal neurological impairment	2
Death	0
Cerebrospinal root injury	1
Blindness	0
Great vessel or organ injury	0
Pneumothorax	1
Unplanned return to the operating room (malpositioned transpedicular screws)	2
Massive blood loss (> 4,000 ml)	1
Total	7

Table 2
Postoperative complications in patients of the study group (according to the criteria proposed by Schwab et al.)

Complication	Number
Death	0
Pelvic organ dysfunctions	0
Deep vein thrombosis	0
Cauda equina syndrome	0
Deep wound infection	11
Motor deficit	0
Myocardial infarction	0
Blindness	0
Pneumonia	6
PATE	0
Reintubation	0
Sepsis	0
Respiratory distress syndrome	1
Pancreatitis and cholecystitis	0
Stroke	0
Unplanned return to the operating room	0
Arrhythmia	0
Great vessel injury	0
Hemopneumothorax	0
Neuropathy (plexopathy)	6
Atelectasis	2
Total	26

The target outcomes of correcting the post-traumatic kyphotic deformities after the staged surgical treatment were achieved completely in our group of patients and were presented in our previous publication [6].

The idea to elaborate a classification of post-traumatic deformities with allowance for the risks associated with surgical correction seems to be promising in terms of foreseeing risks. Afaunov et al. [12] paid attention to the development of neurological (i.e., intraoperative) complications only, with allowance for neither the type of surgical intervention nor its extent. In the present study, we focused on a particular type of surgical correction, the staged surgical interventions, and assessed the resulting complications.

The rate of complications due to correction interventions for sagittal spinal deformities is 25.0–53.9 %. We used a standardized list of complications elaborated by Carreon et al. [13] and modified by Schwab et al. [8]. These findings were compared with the literature data containing the analysis of complications related to three-column osteotomies in accordance with the abovementioned relevant criteria.

Daubs et al. [14] noted that complications developed in 37 % out of 46 patients aged older than 60 years who had been operated on; the rate of severe complications reached 20 %. Auerbach et al. [2] studied the outcomes of PSO and VCR in a group consisting of 240 patients and found that the so-called major complications had appeared in 38 % and 22 % of patients, respectively. Kim et al. [3] reported the overall rate of complications of PSO and VCR to be 40.3 % in the group of 233 patients.

According to the multicenter study published by Bianco et al. [15], the incidence of major complications associated with the corrective osteotomies (revealed within the period up to six weeks) was 42 %.

In our study, we assessed complications in 212 patients who had undergone staged surgical interventions. The complications were observed in 34 (16.0 %)

Table 3
Complications in patients with different degrees of kyphotic deformity, n (%)

Degree of local kyphosis, Cobb angle	Intraoperative complications	Postoperative complications
<25 (n = 134)	1 (0.7)	11 (8.2)
26–35 (n = 49)	1 (2.0)	8 (16.3)
>36 (n = 29)	3 (10.3)	4 (13.7)

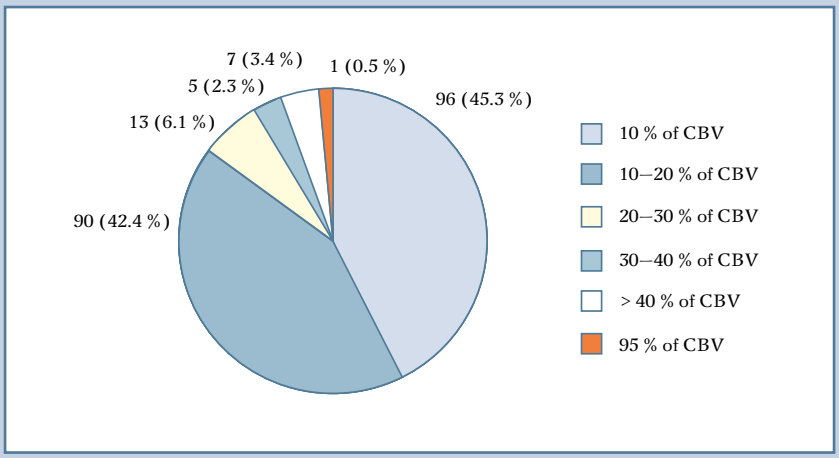

Fig.
Intraoperative blood loss

Table 4
Complications and blood loss during the two-stage and three-stage interventions

Complications	Two-stage (n = 161)	Three-stage (n = 51)
Intraoperative, n (%)	3 (1.9)	4 (7.8)
Postoperative, n (%)	16 (9.9)	10 (19.6)
Total, n (%)	19 (11.8)	14 (27.4)
Mean blood loss, ml	498.5 ± 506.2	758.1 ± 449.7
Blood loss >30 % of the CBV, n (%)	6 (3.7)	6 (11.7)

cases, or in 28 (13.2 %) cases if the criteria proposed by Schwab et al. [8] were applied.

Surgical site infections were the most common postoperative complication in patients who had undergone spinal correction surgeries. The risk factors for development of surgical site infections in patients with this pathology were traumaticity and duration of surgical interventions, as well as significant blood loss. In the literature, the rate of SSI associated with posterior spinal surgery was reported to be 7.6–10.0 % [13, 15]. In the present study, surgical site infections were recorded in eight (3.7 %) patients, mostly after posterior approach (seven patients).

Other most common complications were pulmonary ones, including pneumonia and pulmonary arterial thromboembolism (PATE). The literature review performed by Baron and Albert [16] demonstrated that the rate of pneumonia during spinal correction surgeries varied between 1.0 % and 3.6 %; the rate of pulmonary embolism, between 0.3 % and 14.0 %.

In our study, we found that multisegmental pneumonia and atelectasis had developed in the early postoperative period in six (2.8 %) and two (0.9 %) patients, respectively. No cases of PATE were revealed.

Among intraoperative complications, the most important are the neurological ones. The technique of posterior correction surgeries includes resection of the posterior structures and shortening of the spine and the dural sac containing the CSF. A problem of neurological impairment development after spine shortening has been well studied (including by experimental research). Kawahara et al. [17] studied animals and demonstrated that spine shortening by more than two-thirds of the vertebral segment length was accompanied by buckling of the dural sac and damaging the spinal cord.

The rate of neurological complications following the treatment of post-traumatic kyphosis by spinal osteotomies is 8–20 % [18, 19]. According to the literature data [5, 20, 21] referring to neurological complications of corrective osteotomies, the rate of intraoperative neurological complications is 11.2–27.0 %.

In our opinion, one of the arguments in favor of choosing the staged surgical intervention to treat post-traumatic deformities is the low rate of neurological complications. In our study, this rate was 1.4 % (three patients), including two cases of cerebrospinal neurological impairment and one case of nerve root deficit. We consider the preservation of the posterior vertebral body wall to be a factor ensuring the low rate of neurological complications during anterior correction of spinal deformities. Direct manipulations in close vicinity to the dural sac and the cerebrospinal fluid during anterior interventions are used only upon anterior decompression and if there are strict indications. In general, scientific literature considers neurological impairment during anterior correction to be a casuistic phenomenon [22–24].

Table 5
Complications and perioperative blood loss during surgical treatment of post-traumatic thoracic and lumbar kyphosis

Complications	Localization of post-traumatic kyphosis	
	T3–L1 (n = 156)	L2–L5 (n = 56)
Intraoperative, n (%)	3 (1.9)	4 (7.1)
Postoperative, n (%)	19 (16.1)	7 (12.5)
Total, n (%)	22 (10.3)	11 (19.6)
Mean blood loss volume, ml	497.8 ± 392.0	737.3 ± 701.0
Blood loss >30 % of the CBV, n (%)	13 (8.3)	10 (17.5)

Table 6
Complications and perioperative blood loss during surgical treatment of post-traumatic kyphosis using transpedicular fixation

Complications	Transpedicular fixation	
	open (n = 102)	minimally invasive (n = 110)
Intraoperative, n (%)	6 (5.8)	1 (0.9)
Postoperative, n (%)	18 (17.6)	8 (7.2)
Surgical site infections, n	11 (10.7)	0
Unplanned return to the operating room, n	2 (1.9)	0
Mean blood loss, ml	708.6 ± 586.9	426.5 ± 367.7
Blood loss during the dorsal stage, ml	197.1 ± 155.7	106.0 ± 85.5

Blood loss is one of serious problems of the intraoperative period of corrective spinal surgeries. The technical complexity of surgical interventions leads to risks of massive blood loss, thus affecting the treatment outcomes [21]. Blood loss over 50 % of the total blood volume during the spinal surgery is determined as significant in the literature. It manifests itself as a symptom of physiological burden to which the patient and his/her organism are exposed during the surgery. This symptom must be overcome during the postoperative period [25].

Thus, according to Bianco et al. [15], the blood loss over 50 % was reported in 55 % of patients, and blood loss more than 4,000 ml was documented in 24 % of patients. In their multicenter study, Schwab et al. [8] analyzed the outcomes of surgical treatment of degenerative deformities in 953 patients and identified the massive blood loss of >3,000 ml to be the most common complication and a reliable risk factor of postoperative complications.

It should be noted that significant blood loss is typical of staged surgical interventions to manage injury sequelae. Thus, Suk et al. [26] reported the mean blood loss of 2,892.3 ± 1,360 ml during the combined anteroposterior intervention in 11 patients who had undergone anterior decompression.

In our study, the mean blood loss in patients who had undergone staged surgical interventions was 11.6 ± 11.2 % of the CBV. The blood loss of >50 % of the CBV was observed only in four (1.8 %) patients having fused adjacent vertebrae, in whom the implants that had been displaced into the spinal canal were removed during the surgery. The anterior decompression was carried out in 18 patients during anterior stage of the intervention; the mean blood loss was 1,565 ± 989 ml (between 200 and 4,620 ml), and the mean CBV loss was 33.7 ± 21.6 %.

The study demonstrated that the low mean blood loss during multistage interventions was mostly due to the high contribution of the minimally invasive transpedicular fixation (51.8 %) as one of the intervention stages. The use of this procedure reduced the rate of intra- and postoperative complications by 15.3 % compared to that of the conventional open transpedicular fixation (8.2 % and 23.5 %, respectively). Moreover, no surgical site infections were observed after the minimally invasive transpedicular fixation even in patients with BMI ⩾25 kg/m^2.

Conclusion

It is very important to clearly understand the risks of complications related to surgical interventions when making a decision which surgical correction method to choose to manage a post-traumatic deformity. In our study, the staged surgical interventions aimed at correcting post-traumatic deformities resulted in complications in 14.2 % of patients only (including intraoperative and postoperative complications in 3.3 % and 10.9 % of cases, respectively). Surgical site infections (usually after posterior approach) and pneumonia were the most common complications. The rate of neurological complications was 1.4 %. The complications were more common after three-stage surgical interventions than after the two-stage ones. Correction of lumbar spine deformities was associated with higher complication rate than that of thoracic spine deformities. The complication rate directly depended on the degree of a deformity to be corrected. Minimally invasive transpedicular fixation used as a stabilizing intervention during the staged surgical interventions was associated with a lower rate of surgical site infections and intraoperative blood loss than the transpedicular fixation performed through the conventional median approach.

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