PLANNING OF TRANSPEDICULAR OSTEOSYNTHESIS WITH REPOSITION AND STABILIZATION FOR THORACIC AND LUMBAR SPINE INJURIES

V.S. Kuftov[1], V.D. Usikov[2]
[1]Bryansk City Hospital No. 1, Bryansk, Russia;
[2]National Medical Research Center of Traumatology and Orthopedics n a. R.R. Vreden, Saint Petersburg, Russia

Objective. To evaluate the effectiveness of transpedicular reposition planning in patients with single-level injuries of the thoracic and lumbar vertebrae, depending on the target parameters.

Material and Methods. The study included two representative groups, retrospective and prospective, each of 80 patients with thoracic and lumbar fractures with an average age of 39.2 ± 2.2 years. In the prospective group, morphometry of the spine was performed using CT data, to plan the restoration of the vertical dimensions of the vertebral body and closed decompression of the contents of the spinal canal using a transpedicular repositioning system within up to a month from the moment of injury. Based on the results of morphometry, the main target parameters were calculated, which were aimed at being achieved during the operation.

Results. In the main group, the lumen deficit significantly decreased (from 39.5 ± 4.1% to 14.2 ± 3.1%) versus that in the control group (from 39.3 ± 4.6 to 22.1 ± 5.1%; $p = 0.01$), as well as the cross-sectional area of the spinal canal (from 37.4 ± 5.1% to 14.2 ± 3.1%) versus that in the control group (from 39.6±5.3% to 24.1 ± 5.5%; $p = 0.01$). The anterior vertebral body height was maximally restored, and the magnitude of bone fragment displacement into the spinal canal decreased ($t < 0.05$). A direct correlation was found between the size of the interbody spaces and the height of the vertebral body: between the anterior interbody space and the anterior height of the vertebral body in the main group — $r = 0.485$, in the control group — $r = 0.594$; and between the posterior interbody space and the posterior height of the vertebral body in the main group — $r = 0.309$, in the control group — $r = 0.252$. A strong correlation was obtained between the posterior height of the vertebral body and the spinal canal: $r = 0.625$ in the main group, $r = 0.461$ in the control group. The difference between the initial and calculated angle after surgery was 3.1° ± 0.5° in the main group and 5.6° ± 1.2° in the control group ($p = 0.01$).

Conclusion. Preoperative planning which includes the use of calculated target parameters such as interbody spaces and segmental angles during surgery, allows for the maximum restoration of the vertical dimensions of the injured vertebral body and the performance of closed decompression of the spinal canal contents.

Key Words: vertebral fracture; spinal morphometry; vertebral reconstruction; closed decompression.

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Fractures of the thoracic and lumbar spine account for up to 60% of all spinal injuries [1, 2], and up to 90% of them occur at the thoracolumbar junction T11–L2 [3]. This is associated with the biomechanical characteristics of the transition from the rigid thoracic spine to the mobile lumbar spine and the concentration of stress in this junction segment [4]. The frequency of vertebral fractures in these segments increases, resulting in complications such as spinal cord injury [5].

Decompression of the spinal canal contents with restoration of the biomechanical axis and achievement of spinal stability to prevent secondary deformity are the main objectives in the treatment of thoracic and lumbar spine fractures [6, 7]. Considerable attention is given to indirect decompression of the spinal canal contents, which is achieved through ligamentotaxis and the ligamentous apparatus of the disc without removing the compressing tissue [8, 9]. Transpedicular systems have been developed for indirect decompression of neural structures, allowing independent distraction and correction of lordosis [10].

The surgical outcomes of patients with different types of thoracolumbar injuries indicate that success depends on restoration of the sagittal profile [11, 12]. Meanwhile, it is essential to anatomically restore the vertebral bodies in order to biomechanically and functionally bring the spine closer to its initial condition. This process requires awareness of the initial anatomical parameters of the spine, both linear and angular. Many studies have been focused on identifying morphometric patterns and calculating the necessary parameters between different anatomical structures of the vertebrae [13–15]. The performed statistical correlations between the anatomical structures of the human spine indicate the possibility of calculating the necessary values.

In the correction of spinal deformities, the use of absolute values of segmental angles as a reference is challenged by the diversity of thoracic kyphosis values in normal spinal anatomy [16]. Nevertheless, the necessity of restoring the initial parameters of the injured spinal segment and their expected correlation with the clinical outcome remain a matter of discussion among surgeons [17, 18]. There are currently very few publications on the treatment outcomes of patients with spinal cord injuries depending on the restored sagittal profile.

The objective is to evaluate the effectiveness of transpedicular reposition planning in patients with single-level injuries of the thoracic and lumbar vertebrae, depending on the achieved target parameters.

Material and Methods

The treatment outcomes of patients with single-level injuries of the lower thoracic and lumbar spine were studied in two representative groups of 80 people (mean age – 39.2 ± 2.2 years).

Inclusion criteria for patients in the study: single-level injuries with one or two adjacent discs involved, no congenital anomalies or previous surgeries in the injured spine department.

The control group included 49 (61.3%) men and 31 (38.7%) women (mean age 37.7 ± 3.2 years). The outcomes of the deformity correction, restoration of the vertical dimensions of the injured vertebral body, and the effectiveness of closed decompression of the spinal canal contents were analyzed in a retrospective manner based on CT findings before and after surgery.

The main group consisted of 47 (58.8%) men and 33 (41.2%) women (mean age 40.6 ± 3.1 years). The calculated target values for intervertebral spaces and segmental angles were used to perform deformity correction and closed decompression of the spinal canal contents [19].

To correct spinal deformity, all patients underwent reposition and stabilization transpedicular osteosynthesis within 30 days of the injury time. The mean time from injury to surgery was 11.5 ± 2.3 days in the control group, and 8.2 ± 1.9 days in the main group. All patients received 6 mm diameter monoaxial screws in the midthoracic region and 7 mm screws in the lower thoracic and lumbar spine.

Combined injuries were diagnosed in 36 (45.0%) patients in the control group and in 33 (41.3%) patients in the main group. In the thoracic and lumbar regions, the ratio of injuries was as follows: in the control group – 26/54, in the main group – 24/56.

According to the AO Spine classification, patients were classified as follows: in the control group with A3 injuries – 15 people, A4 – 36, B – 13, C – 16; in the main group – 15, 46, 9, and 10, respectively. Neurological status was evaluated using the ASIA scale: in the control group with grade A – 8 cases, B – 4, C – 19, D – 11, E – 38; in the main group with grade A – 6, B – 2, C – 20, D – 14, E – 38.

The surgery was planned using CT findings in DICOM format with the RadiAnt software after multiplanar reconstruction. A model of the spine consisting of three vertebral bodies and four adjacent intervertebral discs, was used for measurement. The following parameters were evaluated: the vertical dimensions of the vertebral bodies and the intervertebral discs, the diameter and cross-sectional area of the spinal canal, the degree of anterior displacement of bone fragments into the spinal canal (X), and the segmental deformity angle (α). This angle is formed by the line of the inferior cortical plate of the superior vertebra and the line of the superior cortical plate of the inferior vertebra. Bone mineral density was evaluated using the same software based on the mean value in two adjacent vertebrae (Fig. 1).

The following calculations were made using the spinal measurements: narrowing of the spinal canal lumen and cross-sectional area deficit, the anterior (AVH) and posterior (PVH) vertical heights of the injured vertebral body (distances |D–E| and |D1–E1| on the measurement diagrams), the anterior (ISa) and posterior (ISp) interbody spaces (distances |C–I| and |C1–I1|), the segmental angle α, and Δα (the difference between the calculated angle and the angle achieved intraoperatively). The following formulas were used to calculate the desired parameters:

1) deficit of the spinal canal lumen: ((a1 + a3) : 2 × a2) / (a1 + a3) : 2 × 100%;

2) deficit of the cross-sectional area: ((S1 + S3) : 2 × S2) / ((S1 + S3) : 2 × 100 %;

3) an anterior vertebral body height (AVH): (D – E) / ((B – C) + (I – K) : 2) × 100 %;

4) a posterior vertebral body height (PVH): (D1 – E1) / ((B1 – C1) + (I1 – K1):2) × 100 %;

5) an anterior interbody space (ISa): (C – I) / (((B – C) + (I – K)) : 2 + (A – B) + (K – L)) × 100 %;

6) a posterior interbody space (ISp): (C1 – I1) / (((B1 – C1) + (I1 – K1)) : 2 + (A1 – B1) + (K1 – L1)) × 100 %;

7) the segmental angle α = sin-1 (((B – C) + (I – K)) : 2 + (A – B) + (K – L)) – (((B1 – C1) + (I1 – K1)) : 2 + (A1 – B1) + (K1 – L1)) / (I – I1).

Calculations are simplified with data archiving using a specially developed PC program [20].

Surgery was performed with the patient in the prone position with reclination bolsters under the sternum and pelvis. In the control group, a reposition system was installed after placing pedicle screws in the vertebral bodies adjacent to the injured one. After that, traction was performed along the axis with correction of angular deformity. At this stage, the spinal axis was aligned and the shape of the vertebra was restored. Following this, screws (one or two) were placed into the body of the injured vertebra. Subsequently, the reposition system was removed and replaced on both sides, using intermediate screws to allow the spinal canal to continue its reforming process. In the main group, the reposition system was pre-equipped with sleeves for screw placement into the injured vertebra, eliminating the need for system reassembly. During the reposition, the calculated interbody spaces and segmental angles were strictly adhered to and monitored on the image intensifier.

Data were statistically processed using the SPSS Statistica ver. 23 statistical software package. The hypothesis of normal distribution was tested using the Kolmogorov–Smirnov test. Depending on the distribution in the samples, parametric and nonparametric tests were used. The critical value of statistical significance was established at $p < 0.05$.

Results

A comparative analysis of the two groups of patients prior to surgery, with statistical differences calculated, is provided in Table 1.

The groups are similar according to the parameters compared, and the data are statistically significant, except for posterior vertebral height (PVH).

Two parameters were used to evaluate spinal canal stenosis: spinal canal lumen deficit and cross-sectional area deficit, between which a strong direct correlation was observed: Pearson's correlation coefficient was 0.912 in the control group, and 0.853 in the main group. Even though the cross-sectional area deficit reflects the entire spinal canal lumen, the lumen deficit is assessed based on the midsagittal section. Considering the comparability of data on compression of spinal canal contents, it is more practical to use calculations of spinal canal lumen deficit.

According to the results of statistical analysis, the degree of neurological impairment is not significantly associated with spinal canal lumen deficit (Pearson's chi-square test – 0.34). The mean spinal canal deficit is 55.7% in ASIA grade A; 49.1% in grade B; 48.6% in grade C; 37.4% in grade D; and 33.6% in grade E. This is illustrated in Fig. 2 in the form of a box-and-whiskers plot.

Results were evaluated in all patients using follow-up CT scans after surgery. Spinal canal lumen deficit and cross-sectional area deficit were evaluated in 62 patients in the control group and 68 patients in the main group who underwent laminectomy. Therefore, the deficit of spinal canal lumen after surgery in the groups differs significantly: it was 22.1 ± 5.1% in the control group, and in 14.2 ± 3.1% the main group (the Mann–Whitney U test; $p = 0.01$). A comparison of spinal canal lumen deficit before and after surgery in two groups reveals significant differences (t-test for paired samples <0.001).

Postoperative cross-sectional area deficit was as follows: 24.1 ± 5.5% in the control group and 14.2 ± 3.1% in the main group (Mann–Whitney U test; $p = 0.01$). Statistically significant differences were also found when comparing the cross-sectional area deficit before and after surgery (t-test for paired samples <0.01).

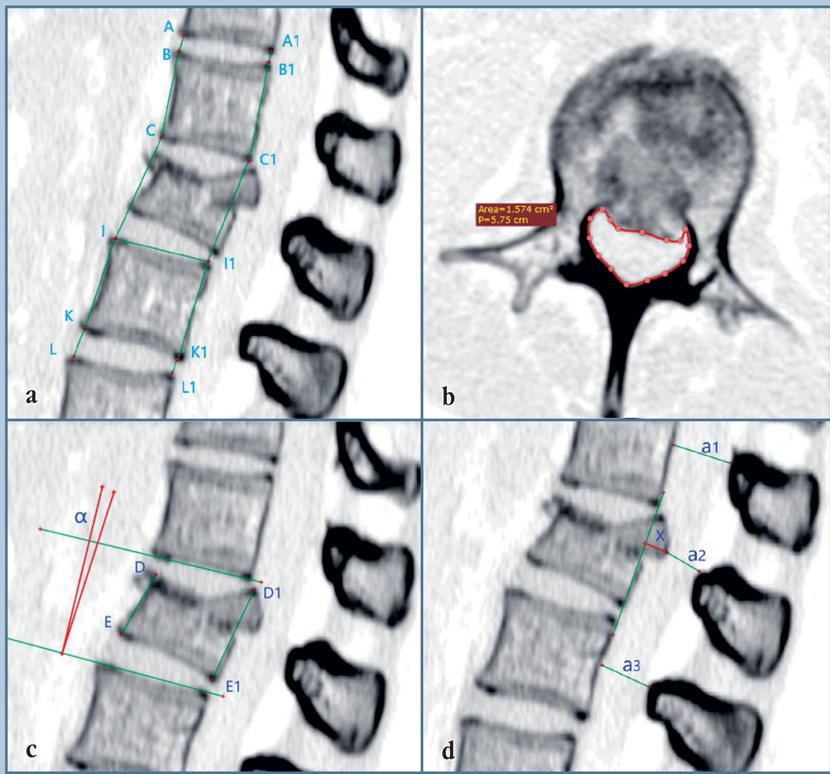

Fig. 1
Measurement scheme: **a** – vertebral bodies and intervertebral discs; **b** – cross-sectional area; **c** – vertical dimensions of the damaged vertebral body and segmental angle; **d** – lumen of the spinal canal (α) and the magnitude of displacement of bone fragments (X) into the spinal canal

The other parameters were calculated for all patients and are shown in Table 2.

The time between injury and surgery also affects the restoration of the vertical dimensions of the injured vertebra. The analysis showed a weak inverse correlation between the degree of restoration of the anterior vertebral body height (ΔAVH) and the time to surgery: the Pearson's correlation coefficient was −0.214 in the control group, and −0.353 in the main group. For restoration of the posterior dimensions of the vertebral body (ΔPVH), the Pearson's correlation coefficient was −0.198 in the control group, and −0.247 in the main group.

A direct correlation was found between the size of the intervertebral spaces (ISa) after surgery and the anterior vertebral height (AVH) of the injured vertebra. The Pearson's correlation coefficient was 0.594 in the control group and 0.485 in the main group. A direct correlation was also found in the restoration of posterior vertebral height (PVH) depending on the size of posterior intervertebral spaces (ISp): 0.252 in the control group and 0.309 in the main group.

The anterior vertebral height (ΔAVH) and the displacement of bone fragments from the spinal canal (ΔX) changed significantly after surgery; t-test for paired samples <0.05. The X value helps to assess the decompression of neural structures, especially in patients who have undergone laminectomy. A moderate direct correlation was found between PVH and ΔX: the Pearson's correlation coefficient was 0.461 in the control group, and 0.625 in the main group.

As an example of the application of preoperative planning techniques, we present the clinical case of patient B, aged 25, with catatrauma. In the course of examination, an isolated uncomplicated fracture of the L1 vertebral body (type A3 according to AO Spine) was found with a 40.7% deficit in the spinal canal lumen and a 39.6% deficit in the cross-sectional area. The measurements required for subsequent calculations are given in Fig. 3. Calculated parameters: anterior interbody space is 40.9 mm; posterior interbody space is 37.4; calculated segmental angle is 6.6°. The patient underwent a 6-screw reposition and stabilization transpedicular osteosynthesis with intraoperative monitoring of the interbody space and segmental angle restoration.

Follow-up CT scans (Fig. 4a) show that the anterior intervertebral space has been restored to 40.9 mm (100%), and the posterior intervertebral space to 38.2 mm (102% of the expected size); the spinal canal lumen deficit has reduced to 11.2%. The anterior vertebral body height was restored to 100.4% of the calculated dimensions, and the posterior vertebral body height was restored to 99.6% of the calculated dimensions. The segmental angle was corrected by 13.9° (from 8.4° to 5.5°) and differed by 1.1° from the calculated angle. A slight discrepancy in angle correction is associated with a 2% overstretching of the posterior intervertebral spaces. In the long term (after 2.5 years), there was no worsening of the deformity of the injured segment, and the calculated individual parameters remained unchanged (Fig. 4b).

The tendency to restore the calculated dimensions of the intervertebral spaces and segmental angle promotes better restoration of the vertical dimensions of the injured vertebral body and closed decompression of the spinal canal.

Discussion

Statistical correlations between anatomical structures of the human spine suggest the possibility of predicting morphometric parameters, which could potentially be used to create simplified geometric models of the spine. Many authors have focused their research on identifying morphometric patterns in vertebrae and calculating the necessary parameters [21–23]. It is widely known that there is currently no reference data reflecting the full range of normal vertebral size variability [24].

It is possible to calculate the exact dimensions of the sagittal profile of the injured spinal segment prior to surgery only after performing a radiography of the spine and pelvis on the day before surgery, with the patient in a standing position and using a variety of spinal and pelvic parameters [25]. It is challenging to conduct such a test on patients with complicated spinal injuries.

Preoperative planning with calculations of the desired target parameters is more evident in type A injuries according to the AO Spine classification. This study examines type C fractures, in which the vertebral body is also injured. In cases of type B and C fractures, where the vertebral body height is not affected, we also consider it necessary to perform calculations to correct the deformity. These calculations involve the height of the intervertebral spaces and the segmental angle.

Table 1

Features of patients in the main and control groups before surgery

Parameters	Control group ($n = 80$)	Main group ($n = 80$)	Significance of differences
Gender (male/female), n	43/31	47/33	Fisher's exact test, 0.32
Thoracic/lumbar spine, n	26/54	24/56	Fisher's exact test, 0.86
Spinal canal lumen deficit, %	39.3 ± 4.6	39.5 ± 4.1	Independent samples t-test, $p = 0.96$
Cross-sectional area deficit, %	39.6 ± 5.3	37.4 ± 5.1	Independent samples t-test, $p = 0.47$
Displacement of fragments into the lumen, mm	6.7 ± 0.7	6.8 ± 0.6	Independent samples t-test, $p = 0.9$
Anterior vertebral body height, %	59.8 ± 3.7	58.4 ± 3.2	Independent samples t-test, $p = 0.54$
Posterior vertebral body height, %	91.8 ± 2.3	88.5 ± 3.2	Mann–Whitney U test, $p = 0.014$
Anterior interbody space, %	74.2 ± 2.6	71.2 ± 3.3	Independent samples t-test, $p = 0.15$
Posterior interbody space, %	87.6 ± 2.0	86.7 ± 1.8	Independent samples t-test, $p = 0.49$
Difference between the initial and calculated angles, degrees	9.7 ± 1.3	10.8 ± 1.5	Independent samples t-test, $p = 0.28$
Bone mineral density, HU	175.5 ± 10.4	169.6 ± 11.4	Independent samples t-test, $p = 0.46$

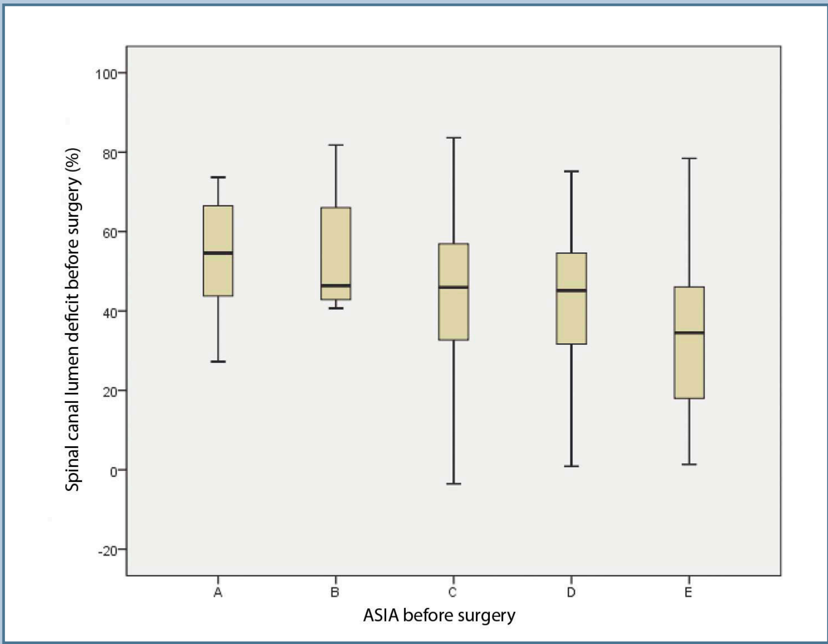

Fig. 2
Spinal canal lumen deficit and the degree of neurological impairment according to ASIA

Numerous external and internal reduction devices have been developed to correct spinal deformity and decompress the spinal canal contents. External repositioning devices allow for full-fledged, gradual correction of post-traumatic multiplanar deformities of the injured spinal segment at a later stage after the injury, but after removal of the device, the achieved correction was lost despite anterior stabilization [26]. Consequently, the external system has not become widely used because of the potential risk of complications and the specific challenges associated with patient management.

Indirect decompression of the spinal canal by distraction and ligamentotaxis is commonly used, which can reduce spinal canal stenosis by almost half [27, 28]. We were able to reduce spinal canal stenosis by 25.3% using the indirect decompression technique. Benek et al. [29] found that the efficacy of indirect reposition decompression of the spinal canal in the lower thoracic and lumbar regions correlates with the percentage of spinal canal compression and is comparable to decompressive laminectomy. The domestic internal transpedicular system "Synthesis" has been developed for closed three-planar reposition and fixation [30].

Indirect decompression of the spinal canal contents using posterior distraction and short-segment stabilization is the optimal way to treat most unstable burst fractures of the thoracolumbar spine and can be effective when the bone fragment is displaced into the spinal canal by no more than 50.0% while preserving the posterior longitudinal ligament [31]. According to Whang et al. [32], ligamentotaxis can be efficient when bone fragment is displaced into the canal by up to 67.0%. An injury to the posterior longitudinal ligament prevents closed indirect decompression of the spinal canal contents [33]. If there is doubt about the outcomes of decompression, E.K. Valeev et al. [34] suggest performing intraoperative contrast imaging of the anterior epidural space.

In cases of burst fractures of the thoracic and lumbar vertebrae, the efficacy of spinal canal remodeling through posterior and anterior approaches was studied depending on the shape and type of displacement of bone fragments of the posterior wall of the injured vertebrae [35]. Ligamentotaxis through the posterior approach with transpedicular fixation is considered effective for large bone fragments filling the entire interpedicular space in the cranial part of the spinal canal. Remodeling of the spinal canal through the anterior approach using the technique developed by the authors is

Table 2
Features of patients in the main and control groups before surgery

Parameters	Control group ($n = 80$)	Main group ($n = 80$)	Significance of differences (Mann–Whitney U test)
Displacement of fragments into the lumen, mm	3.9 ± 0.3	3.1 ± 0.3	$p = 0.04$
Anterior vertebral body height, %	86.5 ± 2.6	94.5 ± 1.6	$p < 0.001$
Posterior vertebral body height, %	93.6 ± 4.0	96.4 ± 2.8	$p = 0.05$
Anterior interbody space, %	93.9 ± 1.7	99.7 ± 1.4	$p < 0.001$
Posterior interbody space, %	98.7 ± 1.8	100.6 ± 1.4	$p = 0.16$
Difference between the initial and calculated angles, degrees	5.6 ± 1.2	3.1 ± 0.5	$p = 0.01$

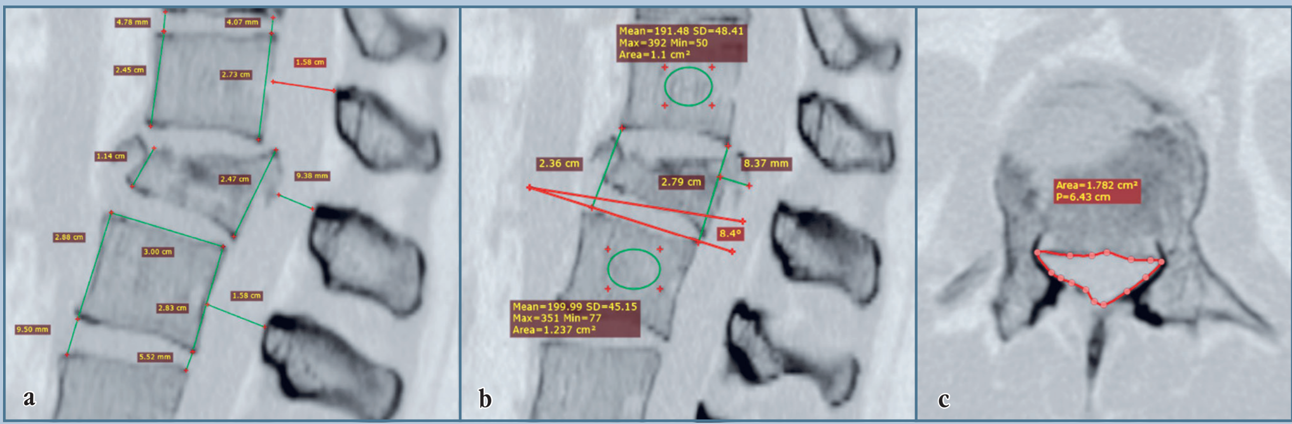

Fig. 3
Morphometry of patient B., 25 years old, based on CT data: **a** – measurement of the vertical dimensions of the vertebral bodies and intervertebral discs; **b** – measurement of the interbody spaces, the magnitude of displacement of bone fragments toward the spinal canal and the mineral density of the adjacent vertebral bodies; **c** – measurement of the cross-sectional area of the spinal canal at the level of injury

efficient for all types of fractures; nevertheless, its successful implementation requires the development of an adequate defect in the vertebral body anterior to the displaced fragments.

In cases of complicated injuries, open decompression and fixation are indicated. Since compression of the spinal cord is located at the anterior aspect in the vast majority of cases, it is preferable to perform decompression through anterior approaches. At the same time, correcting the spinal axis and achieving reliable stabilization through anterior approaches is significantly more complicated compared to transpedicular fixation of the vertebrae [36].

We consider the efficacy of posterior approach reposition both for all types of bone fragment displacement and for all types of spinal injuries (A, B, and C) and associate it with the involvement of the injured vertebra in the process. One could point to the lack of a differentiated approach and be right, but we consider the posterior approach to be the best for performing the entire range of surgeries. Transpedicular spinal reposition effectively eliminates compression in type A injuries, especially in the thoracolumbar junction, where the posterior longitudinal ligament is wider and uninjured.

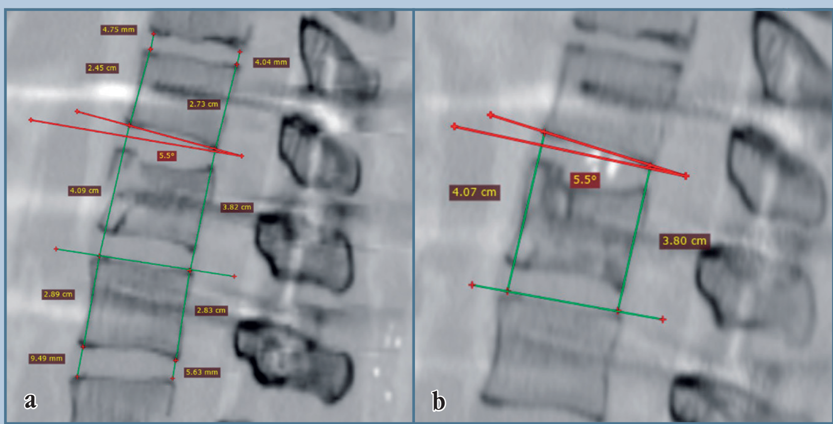

Fig. 4
Control CT scan of patient B., 25 years old: **a** – after surgery; **b** – 2.5 years after surgery

For type B and C injuries, the advantages of the posterior approach are obvious. Patients with neurological disorders will require open decompression with revision surgeries, which is easier to perform using a posterior approach.

Pedicle screw placement in a broken vertebra during ligamentotaxis results in additional decompression of the spinal canal contents and reduced postoperative pain [37]. Clinical and experimental studies indicate the advisability of additional placement of intermediate pedicle screws in injured vertebrae [38]. The use of intermediate screws at the fracture site enhances the efficiency of reposition and stability of the structure, as well as minimizes loss of deformity correction [39].

We were able to place one or two screws for reposition into the injured vertebral bodies. Reduction screws are placed at the last stage, after performing measured spinal traction along the axis with angular correction. It would be extremely challenging to place screws into the injured vertebrae without these procedures, as this could result in additional displacement of the fragments or malpositioning of the screw.

For more effective restoration of vertebral body height, it is suggested to place upper screws at an angle toward the lower cortical plate [40]. Some authors believe that longer screws make reposition more effective [41], while others believe that longer screws in an injured vertebra do not affect fracture reduction but are better at maintaining restored anterior height and reducing loss of kyphosis [37]. The efficiency of fixation was most noticeable when using 7 mm diameter monoaxial screws with involvement of the injured vertebra, especially in type C fractures [42]. The use of 7 mm diameter monoaxial screws placed in front of the anterior cortical plate of the vertebral body is also considered to be a key factor for success in our study.

The quality of spinal reposition and fixation is influenced by bone mineral density [43]. According to CT scan data, a bone mineral density value of 135 HU was qualified as the threshold value between normal and reduced ones.

The time between injury and surgery is significant in the elimination of local post-traumatic deformity [44]. Already after 72 hours, scar tissue forms in the spinal canal, and the abnormal position becomes fixed [45]. High efficacy of closed reposition decompression for injuries in the lower thoracic and lumbar regions has been achieved within ten days [46]. Attempts to recline the spine after three weeks are likely to fail, as by this time the connective tissue has become even more organized, with foci of proliferation of connective tissue elements and the formation of chondrogenic islets and osteoid [47]. In our study, we pointed out the efficacy of spinal reposition one month after injury [48].

Conclusion

Preoperative planning using calculated target values in the form of interbody spaces and segmental angles during surgery maximizes the restoration of the vertical dimensions of the injured vertebra and allows for closed decompression of the spinal canal contents.

The study had no sponsors.
The authors declare that they have no conflict of interest.
The study was approved by the local ethics committee of the institution.
All authors contributed significantly to the research and preparation of the article, read and approved the final version before publication.

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Address correspondence to:
Kuftov Vladimir Sergeyevich
Bryansk City Hospital No. 1,
11 Kamozina str., Bryansk, 241035, Russia,
kuftov@mail.ru

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Vladimir Sergeyevich Kuftov, MD, PhD, neurosurgeon, Bryansk City Hospital No. 1, 11 Kamozina str., Bryansk, 241035, Russia, eLibrary SPIN: 1558-5875, ORCID: 0000-0002-0548-8944, kuftov@mail.ru;
Vladimir Dmitryevich Usikov, DMSc, Prof., senior researcher at the Department of Neurosurgery with Bone Oncology, National Medical Research Center of Traumatology and Orthopedics n a. R.R. Vreden, 8 Baykova str., Saint Petersburg, 195427, Russia, eLibrary SPIN: 3499-8679, ORCID: 0000-0001-7350-6772, usikov@list.ru.