CLASSIFICATION OF POST-TRAUMATIC DEFORMITIES OF THE THORACIC AND LUMBAR SPINE

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Objective. To analyze the working classification of post-traumatic deformities of the thoracic and lumbar spine taking into account the main characteristics of pathological condition of the injured spinal motion segments, spinal cord and roots, affecting the choice of tactics and techniques of surgical treatment.
Material and Methods. The clinical material for the classification development included 124 patients with post-traumatic deformities of the thoracic and lumbar spine operated on after 6 months to 14 years from the time of injury during 2003—2017.
Results. The proposed working classification is based on the systematization of the three orthopedic features. It offers 120 variants of post-traumatic deformities of the thoracic and lumbar spine, each designated by three symbols: a digit, a letter, a digit (for example, 4.B.1 or 2.E.3). An additional option is the four surgical risk gradation of neurological status denoted by the Latin letter N with a digit from 1 to 4.
Conclusion. The classification clearly systematizes numerous variants of post-traumatic deformities of the thoracic and lumbar spine based on the most clinically significant signs. Its application allows justifying the choice of a patient-specific tactical and technical option of surgical treatment.
Key Words: spine, post-traumatic deformities, classification

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To date, a large number of classifications of injuries of the thoracic and lumbar spine are available, which systematize numerous variants of destruction of supporting structures and the level of destabilization of injured spinal motion segments (SMSs), as well as vertebrogenic neurological deficit associated with injuries [3, 6, 9, 10, 12, 15, 16, 19, 20]. Some of these classifications enable solving not only statistical problems. They were developed not so much to facilitate the archiving of clinical material, but primarily to solve practical problems, including preoperative planning, evaluation of the extent of surgical treatment, the choice of one or another method of correction and stabilization of the spine [13—17, 19]. The development of techniques and methods of surgical correction and stabilization of the spine and the accumulation of experience in the treatment of injuries resulted in gradual improvement of injury classification. In our opinion, TLICS (Thoraco-Lumbar Injury Classification and Severity Score) is the most concise classification systematizing the orthopedic component of spine injury [14, 17].

Systematization of late post-traumatic spinal deformities using classifications proposed for fresh injuries is in most cases not accurate, and, in some clinical situations, impossible. Characteristics of a primary injury, as a rule, do not reflect the true picture of impaired supporting function of the spine in a particular patient. Spondylometric parameters of the injured SMSs significantly change during the time elapsed since the injury. Angular displacements increase in most cases. Scoliotic and displacement components of deformity may develop or substantially increase. In some cases, a bone block is spontaneously formed at the injury site, fixing the vertebrae in a vicious position. The presence of fixing metal structures after failed surgery further complicates the situation. In these cases, none of the existing classifications of spine injuries reflects the true pathological state of the injured SMSs or can be fully used as a basis for surgical treatment planning.

The study was aimed at analyzing the variant of classification of post-traumatic deformities of the thoracic and lumbar spine, taking into account the main characteristics of the pathological state of the injured SMSs, spinal cord and roots in the late post-traumatic period.

Material and Methods

Clinical material of the study included 124 patients with post-traumatic deformities of the thoracic and lumbar spine, who were operated on 6 months to 14 years after the injury in 2003—2017. The deformity resulted from failed surgical treatment in 63 of them, diagnostic mistakes and (or) inadequate conservative treatment — in 61. There were 70 males and 54 females aged 18 to 54 years among the patients. Thirty nine patients initially had a spinal cord injury (SCI), 23 patients had neurological deficit

at admission, which was iatrogenic in 5 of them.

Injury at the level of T6—T11 was observed in 28 patients, T12—L1 in 54, L2—L5 in 42. One SMS was injured in 64 cases, 2 — in 55 cases, 3 — in 5 cases. At admission, all patients complained of persistent progressive pain at the area of injured SMSs. Neurological deficit of varying severity was observed in 23 of examined patients, which was evaluated using the Frankel scale [3]. Disorders in the form of lower paraparesis were observed in 15 patients, 6 of them had pelvic dysfunction; lower paraplegia with pelvic dysfunction was observed in 4 cases, radiculopathy without conduction disorders — in 4 cases.

Spondylometric indices of deformities were determined using conventional methods [3, 6, 9] based on the results of radiography, CT, and MRI. Reliable classification of the initial SMS injury based on X-ray images obtained immediately after the injury was possible only in 52 (41.9 %) of 124 patients.

In 72 (58.0 %) patients who were operated on in the late post-traumatic period, the initial radiographs were not available and the injuries were systematized based on the results of X-ray examination in the late period. In this case, there was significantly higher probability of improper definition of the type of the original injury

TLICS type A2 compression fractures were observed in 4 (7.7 %) patients, A3 — in 9 (17.3 %) patients, and A4 — in 11 (21.1 %) patients. B1 distraction injuries occurred in 4 (7.7 %) patients, B2 — in 3 (5.8 %). The most severe (type C) primary injuries were observed in 21 (40.4 %) patients.

In all cases, we proceeded from the assumption that surgical treatment should solve four main tasks: to eliminate or prevent vertebromedullary or vertebroradicular conflicts, normalize anatomical relationships in the injured SMSs, stabilize the injured spine, and perform bone-plastic reconstruction of the ventral portions of injured SMSs. The repertoire of techniques and tools used to solve these problems included transpedicular spinal systems for correction and stabilization of the spine, including an external fixation device (EFD) used for pre-reposition, anterior stabilization systems, correcting interbody implants and vertebral body implants, anterior and posterior spine release techniques (SPO, PSO, VCR, VCD).

There were various technical options of the treatment of post-traumatic deformities of the lower thoracic and lumbar spine. They were systematized with allowance for the number of surgical stages, the order of anterior and posterior surgical procedures, the methods of dural sac decompression, the length of the internal metal fixation of the spine, the number of SMSs involved in the interbody fusion, the possibility of external transpedicular osteosynthesis for pre-repositioning, and spinal systems for posterior or anterior internal stabilization.

In 15 patients, operations were carried out from the posterior approach: PSO or VCR with transpedicular fixation (TPF), including those with preliminary removal of unstable metal structures. The operations via the anterior approach were carried out in 28 patients, including corporectomy, anterior release, decompression, and corporodesis accompanied by fixation with anterior instrumentation, including those with pre-repositioning with transpedicular EFD in 19 patients. Posterior-anterior surgery was carried out in 19 patients: TPF, including those with preliminary removal of unstable metal structures, anterior fusion (19) with additional stabilization with anterior instrumentation (13), including those with pre-reposition using EFD in 15 patients. Posterior-anterior-posterior surgery was performed in 33 patients: posterior release, including that with removal of posterior metal structures, anterior release, anterior decompression, corporodesis, TPF, including that with pre-repositioning using transpedicular EFD in 14 patients, including that with stabilization using anterior instrumentation (360° instrumental fixation) in 14 cases. Anterior-posterior surgical interventions were carried out in 29 patients: anterior release, decompression, corporodesis, TPF, including that with pre-reposition using EFD in 9 patients.

Results

The results of treatment of this group of patients were analyzed and published earlier [1, 2]. This study systematized the most significant orthopedic and neurological signs characterizing the pathological condition of injured SMSs in the long-term post-traumatic period based on the aforementioned clinical material, including spondylometric parameters of injured SMSs, the degree of their rigidity, post-traumatic stenosis of the spinal canal, the nature and dynamics of vertebrogenic neurological deficit. These signs were ranked and formed the basis for the proposed working classification as the most illustrative and easily identifiable ones. Several grades were proposed for each of these characteristics. Variants of possible spondylometric parameters of post-traumatic spinal deformities were divided into 4 grades and labelled by Arabic numerals from 1 to 4 (Table 1). Five grades denoted by Latin letters A, B, C, D, E have been proposed to describe the rigidity of deformity (Table 2). Four grades denoted by digits from 0 to 3 have been suggested to assess the post-traumatic stenosis of the spinal canal (Table 3).

Obviously, the complexity of the clinical situation increases from the first grades (1 or A) to the following ones for the three aforementioned orthopedic signs. Thus, in terms of spondylometric parameters, from the simplest, single-plane angulation corresponding to grade 1, to more complex, two-plane angulation, corresponding to grade 2, followed by grade 3, which, along with angulation, includes rotational and (or) translational displacements. Grade 4 suggests the presence of post-traumatic spondyloptosis (Table 1).

We assume that deformity can be considered as two-plane or even more complex one (grade 2 or higher) only in those cases when displacement in the second plane is large enough and cannot be neglected when correcting the anatomical relationships.

In terms of rigidity, grade A includes deformities not fixed by bone fusion,

grade B — those having anterior or (and) posterior bone block in a vicious position, grades C and D correspond to spinal deformities fixed by posterior or anterior instrumentation regardless of the presence of bone fusion, grade E — deformities with 360° metal fixation (Table 2).

Grades A and B may include both previously operated and non-operated patients, grades D, E and F — only previously operated patients who need revision operations. In these cases, the state of the metal structure will not matter, whether it remains stable or migrates due to bone resorption around the screws, connector unlocking, or fractures.

Post-traumatic stenosis of the spinal canal at the level of injured and deformed segments may be absent or clinically insignificant, not exceeding the reserve spaces, which will correspond to grade 0 (Table 3). Stenosis of the vertebral canal leading to posterior or posterolateral compression of the dural sac, which can be eliminated by laminectomy, corresponds to grade 1. Stenosis provoking anterior compression of the dural sac and anterior form of the vertebromedullary conflict, which can be eliminated using subtotal corporectomy as a possible remodeling option, corresponds to grade 2. Stenosis caused by deformities of the anterior and posterior walls of the spinal canal, provoking circular compression, corresponds to grade 3.

Let us note that these sections of the classification shown in Tables 1—3 do not take into account the quantitative characteristics of the main signs of post-traumatic spinal deformities, but rather systematize them according to qualitative differences. Quantitative characteristics were suggested to be determined using existing methods for assessment of the main spondylometric parameters of SMSs [6, 9]. Additionally, we assume that any grade in term of these three characteristics is assigned only when the value of the corresponding displacements does not allow disregarding them when correcting the anatomical relationships. At the same time, quantitative data must necessarily supplement any possible diagnoses of post-traumatic spinal deformities.

Table 1
Grades of spondylometric parameters of injured spinal motion segments for classification of post-traumatic deformities of the thoracic and lumbar spine

Grade	Spondylometric parameters
1	Angular single-plane deformity (kyphosis)
2	Angular two-plane deformity (kyphosis with lateral inclination)
3	Deformity with displacement and (or) rotation
4	Deformity with displacement and shortening (spondyloptosis)

Table 2
Rigidity grades for classification of post-traumatic thoracic and lumbar spinal deformities

Grade	Characteristics
A	No bone block
B	Bone block in a vicious position
C	Fixing posterior metal structure
D	Fixing anterior metal structure
E	360° metal fixation

Table 3
Grades of traumatic stenosis of the spinal canal for classification of post-traumatic deformities of thoracic and lumbar spine

Grade	Characteristics
0	No clinically significant stenosis
1	Stenosis provokes posterior (posterolateral) compression of the dural sac
2	Stenosis provokes anterior compression of the dural sac
3	Stenosis provokes circular compression of the dural sac

When speaking about post-traumatic spinal deformities, the issue of post-traumatic neurological deficit should not be left beyond the discussion. Obviously, in many cases, clinical manifestations of spinal cord injury in the late period of SCI significantly differ from the symptoms of acute and early periods. In the proposed classification, neurological status grades do not systematize the entire variety of symptoms characterizing the state of neurologic functions in the late period of SCI. For this purpose, there are a lot of classifications scoring both motor and sensory dysfunctions [3]. The surgical risk of the forthcoming surgical treatment with respect to spinal cord functions is the fundamental characteristic of the neurological status in terms of the forthcoming surgical treatment and it forms the basis for the proposed 4 grades. At the same time, when assessing the risk, we do not consider the operation itself, which can be highly traumatic and risky or relatively low-traumatic. We consider the parameters of the anatomical and functional state of the injured SMSs, spinal cord, and roots in the late post-traumatic period, which affect the risk of future surgical treatment in terms of neurological status. The surgical risk may be absent (grade 1), low (grade 2), moderate (grade 3), or high (grade 4) in terms of the potential worsening of

patient's neurological status resulting from surgery. Given this classification structure, neurological parameters characterizing post-traumatic spinal deformities and determining the level of surgical risk with respect to the spinal cord functions line up in an unexpected sequence (Table 4).

The first group, or grade 1, include the most simple and obvious to a surgeon situations that do not bear surgical risk to the neurological status, which occur in the case of severe irreversible post-traumatic neurological deficit. It would seem to be illogical. These are the most serious spinal patients with an unfavorable neurological prognosis. However, this grade is the simplest for the surgeon in terms of the upcoming surgical treatment for post-traumatic deformity, since it is obvious that even not entirely blameless operation will not worsen the existing neurological status in patients with complete spinal cord injury corresponding to Frankel grade A. At the same time, it is unlikely that neurological functions can improve in the postoperative period in these patients. That is, this category of patients is in most cases operated on only for orthopedic indications. Moreover, in the case of severe post-traumatic stenosis of the spinal canal, the surgeon can refrain from full scale remodeling, which in some cases is the most complicated stage of the operation.

A different situation arises in the case of a rapidly progressing neurological deficit. This happens in patients with post-traumatic spinal deformities resulting from late decompensation of the spinal cord function due to the long-term vertebromedullary conflict. We classify these deformities as grade 2. In the cases where neurological status progressively worsens from Frankel grade D to B or even A, technical intraoperative mistakes are unlikely to significantly worsen the spinal cord function. That is, surgical risk of the operation with respect to neurological status is not very high in these patients. Timely and correctly performed surgery can stop the worsening of neurological deficits and recover partially lost functions, which increases surgeon's responsibility for neurological prognosis. This category of patients meeting the criteria of grade 2, always have neurosurgical indications for operations, which are often urgent.

A somewhat higher surgical risk with respect to neurological status arises in the treatment of post-traumatic deformities accompanied by moderate impairments of the spinal cord function without significant dynamics in the long-term period of SCI. In these patients, the severity of neurological disorders most often corresponds to Frankel grades C or D. The operations may have non-urgent neurosurgical indications. In these cases, we assign grade 3 of risk, since there is an obvious risk of iatrogenic worsening of neurological deficit due to technical errors during the operation.

The maximum grade 4 corresponds to high surgical risk in terms of neurological status in treatment of post-traumatic deformities of the thoracic or lumbar spine. In our opinion, it includes the deformities that are not accompanied by neurologic disorders at the time of the operation, resulting from uncomplicated SCI followed by complete or significant partial restoration of the spinal cord function by 2 or more grades according to the Frankel scale. In these cases, a surgeon has the maximum responsibility for the preservation of neurological functions despite the fact that the operation is usually carried out only for orthopedic indications, since it is obvious that postoperative worsening of neurological status can overweigh the most perfect orthopedic result of the treatment on the patient's subjective opinion.

Undoubtedly, the level of surgical risk in terms of the preservation of spinal cord and nerve root function depends on numerous other parameters: the severity of traumatic spinal stenosis, the presence of reserve spaces, the level of spinal deformity, the presence and size of myelopathy foci, etc. They can be taken into account in preoperative planning. Thus, the level of surgical risk in terms of neurological status can be systematized into one of the proposed grades, as well as the three aforementioned orthopedic signs of post-traumatic deformities.

Thus, the proposed classification based on systematization of three orthopedic signs gives a total of 80 variants of post-traumatic deformities of the thoracic and lumbar spine and each of them is labelled using three symbols: a digit, a letter, a digit. For example, 4.B.1 or 2.E.3, etc. Four grades of surgical risk in terms of the neurological status, which can be labelled using Latin letter N with a number from 1 to 4, are an additional option. The classification is schematically shown in Table 5.

The following clinical cases illustrate the proposed working classification of post-traumatic deformities of the thoracic and lumbar spine.

Case 1. Patient D., 26 years old, diagnosed with SCI, late period, fracture and dislocation at the T6—T7 segment, initially TLICS type C, severe post-traumatic deformity, spinal cord rupture, lower paraplegia with pelvic dysfunction, persistent thoracalgia. Six months after injury (Fig. 1).

Deformity is rigid, but without a bone block. There is severe deformity of the spinal canal at the level of injury along the entire perimeter. Its remodeling is possible only by resection of the injured SMSs. According to our classification, these case corresponds to the type 4.A.3 N1 due to traumatic spondyloptosis of T6 without bone fusion, pronounced impairment of the spinal canal anatomy, and irreversible loss of the spinal cord function.

Case 2. Patient Z., 34 years old, with post-traumatic spinal deformity at the level of L1—L2, postlaminectomic defect of L1—L3, and interbody bone block L1—L3 in a vicious position (Fig. 2).

The injury occurred 6.5 years ago. The initial diagnosis was as follows: SCI, explosive fracture of L2 body, subluxation of L1, and lower paraparesis. Initial X-ray images are not available. Possibly, there was TLISC type A4 injury of L2 with spinal cord compression and B2 type distraction injury of the posterior elements in the L1—L2 segment. According to our classification of post-traumatic deformities of the thoracic and lumbar spine, two-plane deformity with a vicious bone block without spinal canal stenosis and

Table 4
Surgical risk grades with respect to neurological status in patients with post-traumatic spinal deformities

Grade	Surgical risk	Vertebrogenous neurological deficit at the time of operation	Possible changes in neurological deficit as a result of surgical treatment	
			Worsening	Improvement
1	No	Severe irreversible	No	No
2	Low	Rapidly progressive	No	Yes
3	Medium	Limited, without significant dynamics	Yes	Yes
4	High	Absent or regressive	Yes	No

with complete regression of neurologic disorders in this patient belong to type 2.B.0 N4.

Case 3. Patient N., 25 years old, with post-traumatic spinal deformity at the level of T12—L2, condition after surgical treatment (TPF of T12—L2, corporodesis of T12—L2, container-type implant), lower distal paraparesis, destabilization and migration of metal structure (Fig. 3).

The time since the moment of injury was 1.5 years. The initial diagnosis was an explosive fracture of L1 body, TLISC type A4. In this case, post-traumatic deformity includes kyphosis and posterior dislocation of T12 up to 45 % of the sagittal size of the vertebral body with fixation using anterior and posterior instrumentation. Vertebromedullary conflict due to anterior compression of the dural sac with limited neurological deficit without significant dynamics. According to our classification, this case should be referred as type 3.E.2 N3.

Discussion

The existing classifications of thoracic and lumbar spine injuries only partially determine the spondylometric parameters of post-traumatic deformities that may occur in a long-term post-traumatic period. The grades of the spondylometric parameters in the proposed classification largely depend on the parameters of the primary injury, but at the same time do not match them completely due to the tendency to worsening and complication. Moreover, classification of fresh injuries does not take into account some important signs of post-traumatic deformities, such as rigidity, possibility of bone fusion in a vicious position, and the presence of destabilized metal structures, although they can significantly influence the tactics of treatment and the choice of techniques for correction and stabilization of the spine. The signs used to develop the aforementioned working classification of post-traumatic spinal deformities are always clearly determined when using modern diagnostic tools and they are usually taken into account in preoperative planning of surgical treatment of this category of patients.

There are publications suggesting the algorithms to select certain aspects of surgical treatments of patients with post-traumatic deformities. The Universal classification of thoracic and lumbar vertebral injuries of the Association of Osteosynthesis based on primary injury was used to propose a rationale for selecting a combined surgical approach for the treatment of post-traumatic deformities [8]. Additionally, certain techniques for correction and stabilization of the spine can be selected on the basis of the Universal classification of thoracic and lumbar vertebral injuries of the Association of Osteosynthesis based on the primary injury supplemented with additional descriptive signs, characterizing the state of injured SMSs [7]. In operations for rigid kyphotic deformities, the extent of the release stage of surgical treatment is determined on the basis of quantitative spondylometric characteristics of deformity [4].

In this paper, we did not pursue the objective to develop an algorithm for preoperative planning of surgical treatment of patients with post-traumatic spinal deformities on the basis of the proposed classification. Nevertheless, when considering the grades of the first characteristic of the proposed classification with allowance for the aforementioned literature data [4, 8] and our clinical observations [1, 2, 7], it is clear that in the case of grade I deformities with required correction up to 25–30°, correction and stabilization of the spine can be performed using only anterior approach. In the case of deformities characterized by the same angular values but belonging to grades 3 or 4, the only anterior approach will be insufficient. Posterior approaches with vertebrectomy or shortening resections or combined posterior and anterior approaches will be required [8].

In the case of grade A (in terms of the second characteristic) deformities in some patients with moderate grade 1 or 2 spondylometric disorders characterized by moderate angular deviations, it is possible to apply the techniques used in the surgical treatment of fresh spinal injuries. In the case of high angular deviations or more complex spondylometric parameters (grades 3, 4) but without bone fusion or fixing metal structures, closed preliminary correction of the anatomical relationships using the EFD is possible followed by subsequent stabilization of the spine with anterior or posterior instrumentation [1, 2, 7]. In grade B patients in terms of rigidity, the operation should involve quite traumatic release stage including osteotomy of the vicious bone block via the anterior, posterior, or combined approach [4]. Percutaneous application of EFV as an independent repositioning tool is impossible in these cases. Grades C, D and E assume the presence

Table 5
Schematic classification of post-traumatic deformities of the thoracic and lumbar spine

Complexity of spondylometric characteristics	1					2					3					4				
Rigidity level	A	B	C	D	E	A	B	C	D	E	A	B	C	D	E	A	B	C	D	E
Grades of spinal stenosis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
Grades of neurological risk	N – 1, 2, 3, 4																			

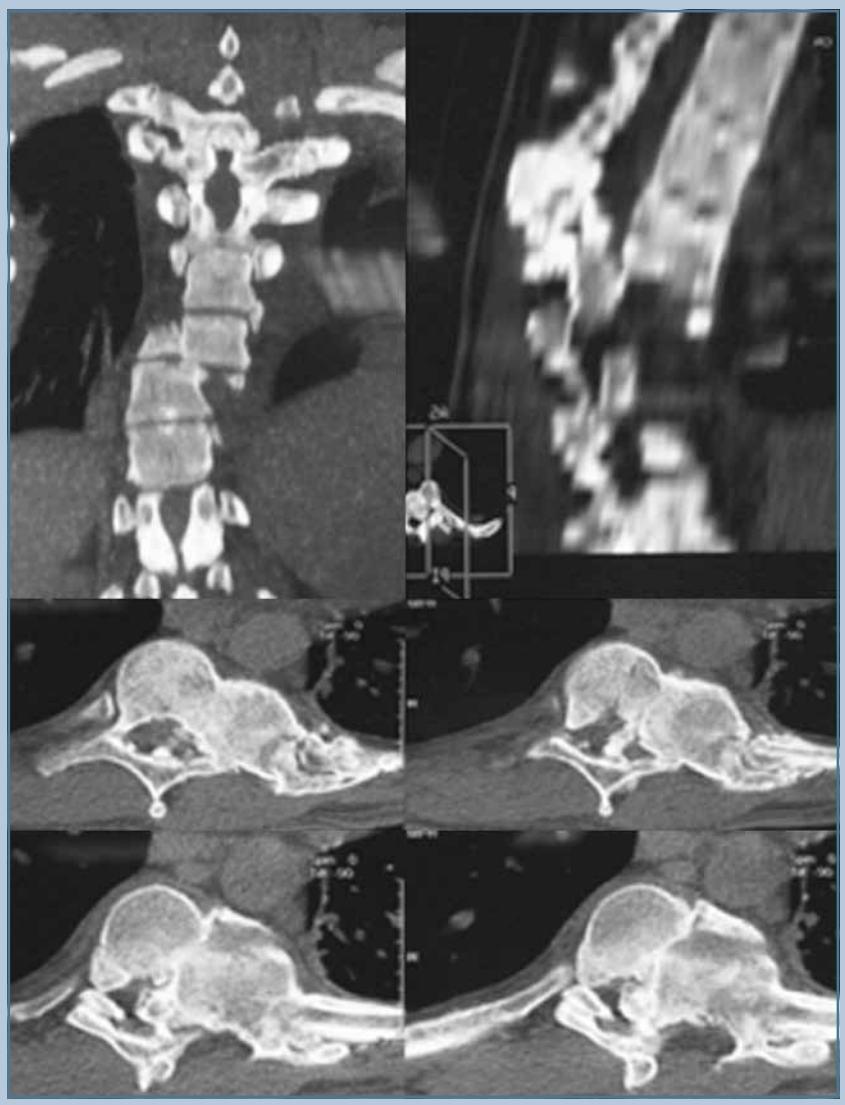

Fig. 1
CT of patient D., 26 years old, with spinal cord injury, late period

of fixing metal structures. In these cases, surgical treatment must begin with approaches that enable their removal: posterior for grade C, anterior for grade D, and combined for grade E. Further use of the possibilities of these approaches for implementation of the main stages of surgical treatment depends on surgeon's preferences, experience, and technical equipment.

The issue of surgical risk in the treatment of patients with post-traumatic spinal deformities is extensively covered in special literature [5, 11, 18]. However, it should be noted that publications focusing on this problem consider the risk associated with the characteristics of the operations themselves rather than the state of the injured patient's spine. In our study, we suggest risk grades in terms of neurological status, which depend only on the anatomical and functional state of the injured SMSs, spinal cord, and nerve roots in the late post-traumatic period. In the case of grade 1 deformity, any the most aggressive methods can be used for mobilization and correction of anatomical relationships in the injured SMSs (PSO or VCR). In the cases of moderate or high risk of neurological complications corresponding to grades 3 and 4, including those after removal of metal structures, it is advisable to refrain from these repositioning technique in favor of staged surgical treatment [8] or low-traumatic and safe correction using EFD [1, 2].

In this section, we briefly discussed the potential feasibility of well-grounded selection of various tactical and technical options of surgical treatment of patients

Fig. 2
X-ray and CT images of patient Z., 34 years old, with post-traumatic spinal deformity at the level of L1—L2

with post-traumatic spinal deformities in various clinical situations. Experienced specialists in spine surgery might disagree with our opinion and prefer other technical and tactical approaches to the treatment of post-traumatic deformities in the aforementioned situations. Nevertheless, the availability of classification as a tool for systematization of various post-traumatic deformities will enable planning of the forthcoming operations in accordance with surgeon's personal experience and instruments used.

Conclusion

The proposed classification clearly systematizes numerous variants of post-traumatic deformities of the thoracic and lumbar spine according to the most clinically significant signs determined in the late post-traumatic period. Classification can be discussed by interested specialists and further form the basis for the development and validation of the algorithm for selection of the surgical procedure for patients with post-traumatic deformities of the thoracic and lumbar spine.

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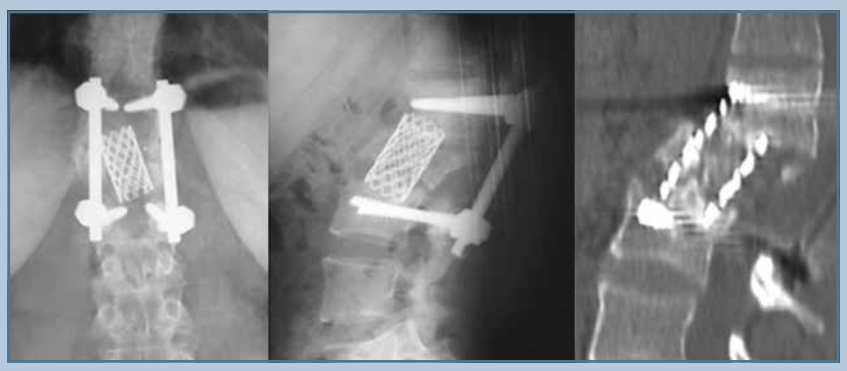

Fig. 3
X-ray and CT images of patient N., 25 years old, with post-traumatic spinal deformity at the level of T12—L2

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