METHOD FOR PREVENTING FRACTURES OF ADJACENT VERTEBRAE DURING TRANSPEDICULAR FIXATION IN OSTEOPOROSIS

I.V. Basankin[1], K.K. Takhmazyan[1], A.A. Afaunov[2], D.A. Ptashnikov[3], O.N. Ponkina[1], N.S. Gavryushenko[4], S.B. Malakhov[1], V.K. Shapovalov[1]
[1]Regional Clinical Hospital No. 1 n.a. Prof. SV Ochapovsky, Krasnodar, Russia
[2]Kuban State Medical University, Krasnodar, Russia
[3]Russian Research Institute of Traumatology and Orthopedics n.a. RR Vreden, St. Petersburg, Russia
[4]Central Institute of Traumatology and Orthopaedics n.a. NN Priorov, Moscow, Russia

Objective. To substantiate experimentally a method for preventing adjacent vertebra fractures during cement transpedicular fixation of vertebral fractures in osteoporotic patients.
Material and Methods. An experimental study included the assessment of overall strength of 10 cadaver blocks of T10–L4 vertebral segments with simulated Magerl's type A fracture at the L_1 level and transpedicular fixation at the T12–L2 levels with four-screw system and cement augmentation. In five control blocks, only cement augmented transpedicular fixation was performed after the L1 fracture simulation. In five blocks of the study group it was supplemented by vertebroplasty at T11 and L3 levels cranial and caudal to the level of fixation. Load testing of the blocks was carried out by destruction under the influence of a vertically directed force.
Results. Vertical loading of anatomical specimens in the control group (average of 0.84 kN) caused Th_{11} vertebral body fractures. In the study group, the vertebrae augmented by vertebroplasty were resistant to loading. Fractures occurred in the T10 vertebral bodies (over the vertebra with vertebroplasty) under the average load of 1.91 kN.
Conclusion. Vertebroplasty of the vertebra overlying the level of transpedicular fixation is an effective way to prevent its fracture.
Key Words: spine, fracture, experiment, osteoporosis.

Please cite this paper as: *Basankin IV, Takhmazyan KK, Afaunov AA, Ptashnikov DA, Ponkina ON, Gavryushenko NS, Malakhov SB, Shapovalov VK. Method for preventing fractures of adjacent vertebrae during transpedicular fixation in osteoporosis. Hir. Pozvonoc. 2016;13(3):8–14. In Russian.*
DOI: http://dx.doi.org/10.14531/ss2016.3.8-14.

The number of osteoporotic patients with lesions of the thoracic and lumbar spine is steadily increasing [9]. Transpedicular fixation (TPF) is the main method for treating this pathology in case of deformity and significant compression of vertebral bodies. It is well known that the strength of TPF with cement implantation of screws significantly exceeds that of the standard cementless [1, 3] procedure and this method prevents destabilization of fixated vertebral-motor segments (VMS). However, practical experience of using of two-segment or longer fixation in surgery of vertebral fractures in osteoporotic patients demonstrated that the load on the adjacent VMS increases after the treatment and leads to fractures of the vertebra adjacent to those fixated during the procedure [4]. The state of the vertebra adjacent to the transpedicular system causes issues even in the absence of osteoporosis. The cadaveric researches and clinical observations of patients with extended TPF revealed susceptibility of a vertebra cranial to the transpedicular system to stress fracture under the conditions of normal everyday activity of a patient [5, 6, 8]. The search for optimal ways of preventing such complications is an acute problem of modern vertebrology. The purpose of the study is experimental substantiation of the method of prevention of fractures of adjacent vertebrae in case of cemented augmentation of TFP in osteoporotic patients.

Material and methods

The cadaveric material obtained from ten women over the age of 66 who died from various somatic diseases was used in the study. The patho-anatomical department extracted VMS blocks of T10 to L4 (7 vertebra). Care was taken to preserve the integrity of the vertebrae and intervertebral discs, as well as the capsular-ligament apparatus. Paravertebral muscles were completely removed.

All extracted blocks were examined by X-ray in two projections, CT and CT-densitometry. CT and CT-densitometry of the blocks were performed on a 128-slice tomograph “CT Somatom Sensation 24 Open”.

The criteria for inclusion in the study: absence of destructive changes in the spine, absence of pronounced frontal or sagittal deformities, signs of ankylosing spondylitis, presence of X-ray and densitometric signs of osteoporosis (T-test value is lower than -2.5).

An imitation of unstable L1 type A fracture (according to the classification of Magerl, Aebi, Nazaian which is included in the Universal Classification of AO/ASIF fractures of 1996) was performed on all blocks, with the destruction of up to 40–50 % of the bone mass of the vertebral body in its cranial part. It was achieved by resection of the cranial part of L1 body together with the T12–L1 intervertebral disc. It created conditions similar to real life ones, where the loss of the support of the ventral parts of the vertebra creates prerequisites for kyphotic deformation. The choice of L1 was not accidental, since according to statistics this vertebra is most often affected [7].

After damaging L1 on all blocks, TPF of T12–L2 region were simulated using a 4-screw transpedicular system with cement implantation of the screws. The amount of bone cement to be added to strengthen the screws was 7–8 ml per vertebra. The correctness of the screws position was monitored during the implantation with a C-arm with an electron-optical converter “Siemens Arcadis”, and after completion of the fixation, using a stationary X-ray apparatus “Philips Duo Diagnost”. Therefore, in each block of the anatomical specimen two vertebrae above and two vertebrae below the transpedicular system remained intact. All anatomical blocks were subsequently divided into 2 groups of 5 blocks each.

Control group: blocks with simulated L1 fracture, 4-screw T12–L2 TPF system on straight bars with cement implantation of screws; two vertebrae above and below of the fixated VMS are intact.

Study group: blocks similar to the blocks from the control group, but with additional vertebroplasty of T11 and L3 bodies; vertebroplasty was performed by inserting bone cement through a transpedicularly installed 13G needle, into the bodies of the corresponding vertebrae; the volume of cement was 7–8 ml per vertebra, which corresponds approximately to 25 % of the volume of the vertebral body [2]; the degree of filling of the vertebra was monitored by X-ray.

The anatomical blocks of the vertebral segments in the study and control groups, which were prepared according to the procedure described above, were subjected to mechanical action along vertical axis to determine their overall strength. Load testing were carried out in the testing laboratory of the Priorov Central Institute of Traumatology and Orthopaedics (Moscow) on the universal servo-hydraulic test machine “Walter + bay ag” LFV-10-T50 (Switzerland).

The examined blocks of vertebral segments were fixed on special platforms between the closing traverses of the testing machine. The proximal node of the platform, which fixed the cranial vertebra of the tested block, was attached to a pressure sensor that was rigidly connected to a movable traverse of the testing machine. The distal node of the platform, which fixed the caudal vertebra of the tested specimen, was fixed in a three-jaw grip firmly attached to the axis of the motor that was rigidly fixed on the immovable traverse. The distance between the traverses was initially set in accordance with the vertical dimensions of the tested specimen (Fig. 1). Before the start of the test, zero position of the sensor was established. The machine was turned on in a compression mode. The increasing vertically directed testing load was applied with a speed of traverses closing of 5 mm/min. The compression of the blocks was carried out with an effort from 0 to 3–5 kN.

Under the influence of the increasing load, visual observation initially revealed the appearance of slight kyphotic deformation cranially to the level of TPF. It was followed by gradual destruction of the tested specimen, accompanied by characteristic sound and further increase in deformation without proportional increase in the load. The data obtained was processed on a computing unit of a universal testing machine. The deformation parameters of the tested blocks by the applied load was recorded in the form of the diagrams using “vertical load (N) – compression deformation (mm)” coordinates. The test determined the vertical load required to cause initial local destruction (fractures) in the prepared anatomical blocks of the vertebral segments. The fractures were reflected on the diagrams in a form of oscillations of the line that describe relationships between the deformity caused by compression and the load applied. These are the parameters that characterize the overall strength of the studied anatomical blocks of the vertebral segments. Angular deformations of the vertebral segments under investigation that were caused by vertically directed force were recorded using digital photography and video recording. The diagrams obtained were used to create tables describing the dependence of the tested specimen deformation on the applied load for subsequent analysis. The load resolution in the tables was 20 N. The quantitative characteristics of the outcomes of the conducted experiments were subjected to statistical processing and standard error of the mean values were determined.

After the stress test was completed, all blocks were subjected to control X-ray and CT examinations to visualize the fractures. The state of the transpedicular system was monitored to identify the signs of its destabilization. A search for local destruction (fracture) zones was performed in the bone mass of the vertebrae with the implanted screws and those located cranially and caudally to

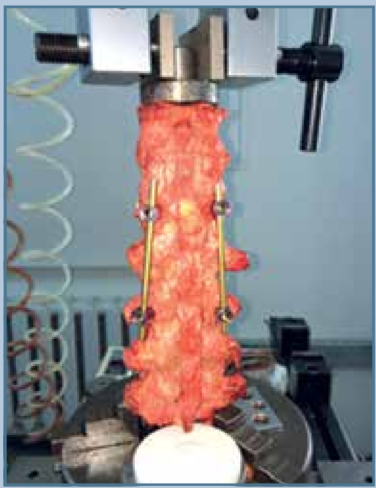

Fig. 1
Anatomical block of vertebral segments before stress testing

the VMS that was fixated by transpedicular systems. The data of X-ray study was compared with the graphical diagrams showing the fracture.

Results

X-ray and CT studies of blocks of vertebral segments did not reveal signs of destabilization of the 4-screw transpedicular systems with cement implantation of the screws into T12 and L2 vertebrae in any of the 10 experiments in the study and control groups. There were no fractures of the vertebrae into which the screws were implanted using bone cement or fractures or unblocking of the elements of metal constructions.

In the control group, the first graphic fluctuations corresponding to a fracture were detected in the range 0.78–0.94 kN (average 0.84 ± 0.3981; Fig. 2). Increasing the load to 1.24–1.6 kN (an average of 1.47 ± 0.39831) resulted in more oscillations in the chart and the appearance of visible kyphotic deformation, indicating more severe destruction of anatomical specimen.

The X-ray and CT examinations performed after the testing revealed fractures of T11 vertebra adjacent to the transpedicular system in all blocks in the control group. There were no X-ray signs of fracture in other vertebrae in the control blocks. Fig. 3 shows the X-ray diffraction patterns before and after the experiment in an anatomical block from the control group which did not underwent vertebroplasty of vertebral bodies adjacent to TPF level.

The use of the same procedure for stress testing of the study group specimen produced data that were significantly different from the control group. The first graphical oscillations corresponding to a fracture were found in the range 1.78–2.05 kN (on average 1.91 ± 0.40566). Signs of more severe fracture first appeared in the range of 2.12–2.88 kN (on average 2.51 ± 0.40566).

Fig. 4 graphically represents relationships between deformation of the tested block of the vertebral segment in the study group and the applied vertical load, revealing a fracture of T10 vertebra (above the vertebrae which underwent vertebroplasty).

The presented graph shows that gradual increase of the load to the value of 2.05 kN does not lead to any oscillations. Only after the load level of 2.05 kN is reached (2.05–2.02 kN), did the first graphic oscillation corresponding to the first mircofracture in the body of the appear. After slight increase in the load, there is a more serious dip in the plot (2.14–1.94 kN). Further increase in the load leads to the destruction of deeper trabeculae.

Subsequent X-ray study proved that T11 and L3 vertebrae adjacent to the transpedicular system, which underwent vertebroplasty, are resistant to mechanical stress testing. There were no cases of fractures in the indicated vertebrae. However, fractures of the adjacent T10 vertebra, located above T11 vertebra, which underwent vertebroplasty, were diagnosed in all five specimens in the study group.

Fig. 5 shows X-ray diffraction patterns in the anatomical specimens of the study group, where vertebroplasty of vertebral bodies adjacent to the level of the TPF were performed, before and after the stress testing.

The data collected in the course of the experiment and describing the load required to cause vertebral fractures of

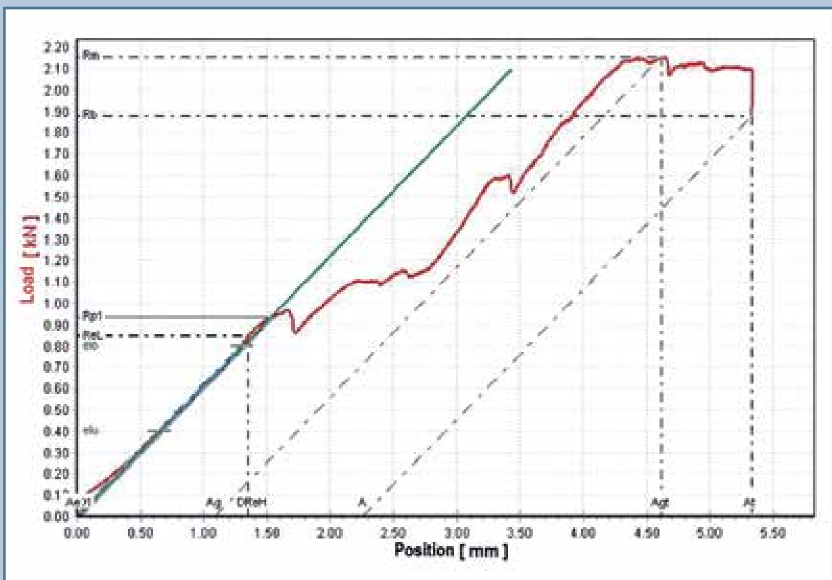

Fig. 2
Relationship between the deformation of the vertebral segment and the applied vertical load in the control group

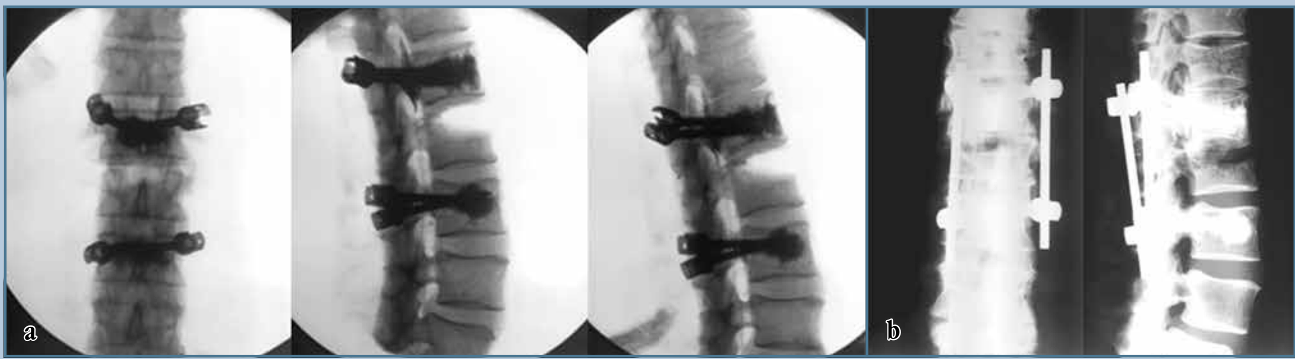

Fig. 3
Radiographs of the vertebral segment of the control group: **a** – before the stress testing; cement implantation of screws into T12 and L2, the cranial part of the L1 body with the overlying disc is resected; **b** – after stress testing, a fracture of the T11 body was diagnosed, evident as a loss of the vertical body size, presence of fracture lines in the lateral projection, and a decrease in the vertical size of the vertebral body on the left side in a straight projection

the adjacent VMS are summarized in the Table with the reference to the group and the affected vertebra.

In Fig. 6, the overall strength of the investigated blocks of the vertebral segments in the study and control groups is plotted against the value of the vertically directed mechanical force, necessary to cause local fractures.

Discussion

Analysis of the obtained data allows us to conclude that the gradual increase of the vertically directed load on the anatomical blocks of the vertebral segments of the control group initially leads to slight kyphotic deformation mainly caused by the compression of T11–T12 disc. It creates most unfavorable biomechanical conditions for the ventral sections of T11 in case of further increase in the vertically directed force. As a result, once a relatively small force of 0.78–0.94 kN is applied, it causes local destruction in the ventral part of the bone mass of T11 bodies. Further increase in the load leads to deeper destruction of this vertebra trabeculae, which is reflected on the diagram in the form of several more dips characterizing the ongoing fracture processes, which progress and cause pronounced kyphotic deformation. Therefore, the experiments with blocks of vertebral segments of the control group showed that the ventral parts of the T11 body located directly above the transpedicular system are the most susceptible to vertical load.

There were no fractures in the cement augmented Th11 bodies in the experiments with blocks of vertebral segments in the study group under similar conditions. The blocks withstood efforts up to 1.78–2.05 kN, which is 1.7–2.3 times higher than the values for the control group. Fractures only occurred in non-cemented Th10 bodies, that is, above the vertebra which underwent vertebroplasty (T11). Therefore, vertebroplasty of Th11

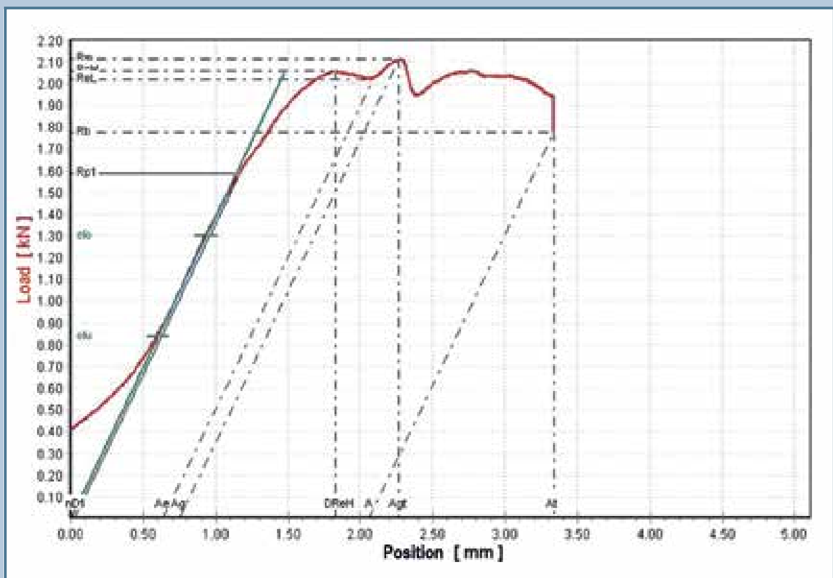

Fig. 4
Relationship between the deformation of the vertebral segment and the applied vertical load in the study group

vertebra above the TPF level is an effective way of preventing its fracture and can be considered as preventive measure against stress fracture and proximal kyphosis above the fixated VMS.

Conclusions

1. In the vertically directed force experiments the weakest point in the anatomical specimens of T10–L4 vertebral segments with simulated Magerl's type A fracture at the L1 level and transpedicular fixation at the T12–L2 levels with four-screw system and cement augmentation is the body of the adjacent vertebra T11 cranial to the level of fixation.

2. The bone cement augmentation of the body of the adjacent vertebrae T11, located cranially to the level of fixation, increases the overall strength of the anatomical specimens of T10–L4 vertebral segments with simulated Magerl's type A fracture at the L1 level and transpedicular fixation at the T12–L2 levels with four-screw system and cement augmentation by 1.7–2.3 times.

3. Vertebroplasty of the vertebra above the level of the TPF is an effective way of preventing its fracture, and can be considered as preventive measure against stress fracture and proximal kyphosis above the fixated VMS in osteoporotic patients.

4. Preventive vertebroplasty of the vertebra caudal to the level of fixation is inexpedient due to insignificant risk of its fracture.

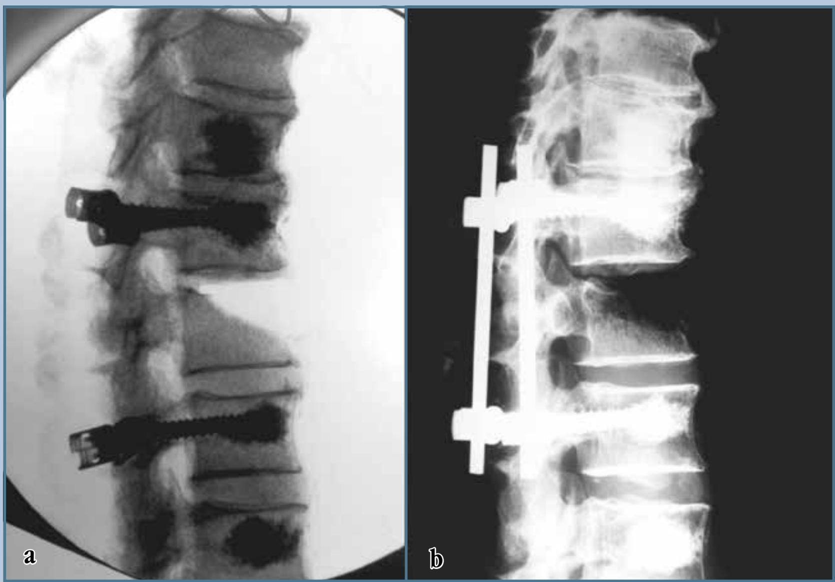

Fig. 5
Radiographs of the vertebral segment of the study main group: **a** – before the stress testing; **b** – with T11 and L3 vertebroplasty after the experiment, the vertebra T11 (with vertebroplasty) is resistant to load, a fracture of the cranial vertebra T10 over the vertebra with vertebroplasty is detected

Table
The characteristics of the anatomical specimens by the group and the parameters of the applied force that caused a vertebral fracture

Group	Study material	Sex, age, years	T-test value	The first signs of fracture, kN	Rough destruction, kN	Fractured vertebra
Control	Block 1	F, 66	2.47	0.87	1.52	T11
	Block 2	F, 71	2.87	0.94	1.60	T11
	Block 3	F, 75	3.48	0.91	1.45	T11
	Block 4	F, 68	2.49	0.80	1.32	T11
	Block 5	F, 80	3.40	0.78	1.24	T11
	Average	0.84000 ± 0.39831			1.47000 ± 0.39831	
Study	Block 1	F, 63	2.51	1.78	2.12	T10
	Block 2	F, 78	2.39	1.91	2.46	T10
	Block 3	F, 81	3.89	1.80	2.51	T10
	Block 4	F, 79	3.36	2.05	2.78	T10
	Block 5	F, 67	2.67	1.95	2.74	T10
	Average	1.91000 ± 0.40566			2.51000 ± 0.40566	

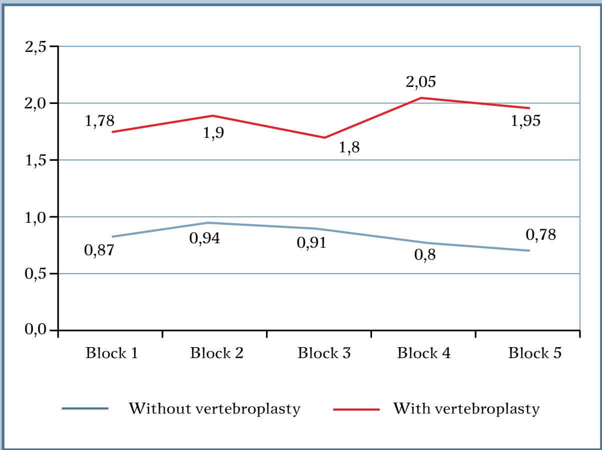

Fig. 6
Indicators of the overall strength of the anatomical blocks of the vertebral segments of the study and control groups under investigation against vertically directed mechanical force

References

1. **Afaunov AA, Basankin IV, Takhmazyan KK.** Analyzing the results of application of cement transpedicular screw fixation in treatment of thoracic and lumbar injuries of the spine in osteoporosis. Prospects of Spine Surgery: Materials of the 4th Congress of Interregional Public Organization «Association of Spine Surgeons» with international participation. Novosibirsk, 2013:10–16. In Russian.
2. **Manukovsky VA.** Vertebroplasty in the treatment of spinal pathology (clinical experimental study): Abstract of MD/PhD Thesis. St. Petersburg, 2009. In Russian.
3. **Burval DJ, McLain RF, Milks R, Inceoglu S.** Primary pedicle screw augmentation in osteoporotic lumbar vertebrae: biomechanical analysis of pedicle fixation strength. Spine. 2007;32:1077–1083. DOI: 10.1097/01.brs.0000261566.38422.40.
4. **Fernandez-Baillo N, Sanchez Marquez JM, Sanchez Perez-Grueso FJ, Garcia Fernandez A.** Proximal junctional vertebral fracture-subluxation after adult spine deformity surgery. Does vertebral augmentation avoid this complication? A case report. Scoliosis. 2012;7:16. DOI:10.1186/1748-7161-7-16.
5. **Hassanzadeh H, Jain A, El Dafrawy MH, Ain MC, Mesfin A, Skolasky RL, Kebaish KM.** Three-column osteotomies in the treatment of spinal deformity in adult patients 60 years old and older: outcome and complications. Spine. 2013;38:726–731. DOI: 10.1097/BRS.0b013e31827c2415.
6. **Lau D, Clark AJ, Scheer JK, Daubs MD, Coe JD, Paonessa KJ, LaGrone MO, Kasten MD, Amaral RA, Trobisch PD, Lee JH, Fabris-Monterumici D, Anand N, Cree AK, Hart RA, Hey LA, Ames CP.** Proximal junctional kyphosis and failure after spinal deformity surgery: a systematic review of the literature as a background to classification development. Spine. 2014;39:2093–2102. DOI: 10.1097/BRS.0000000000000627.
7. **Lehman RA Jr, Paik H, Eckel T, Helgeson MD, Cooper PB, Bellabarba C.** Low lumbar burst fractures: a unique fracture mechanism sustained in our current overseas conflicts. Spine J. 2012;12:784–790. DOI: 10.1016/j.spinee.2011.09.005.
8. **Martin CT, Skolasky RL, Mohamed AS, Kebaish KM.** Preliminary results of the effect of prophylactic vertebroplasty on the incidence of proximal junctional complications after posterior spinal fusion to the low thoracic spine. Spine Deformity. 2013;1:132–138. DOI: 10.1016/j.jspd.2013.01.005.
9. **Yang Z, Griffith JF, Leung PC, Lee R.** Effect of osteoporosis on morphology and mobility of the lumbar spine. Spine. 2009;3:E115–E121. DOI: 10.1097/BRS.0b013e3181895aca.

Address correspondence to:
Afaunov Asker Alievich
Zakharova str., 29, ap. 10, Krasnodar, 350007, Russia,
afaunovkr@mail.ru

Received 16.02.2016

Igor Vadimovich Basankin, MD, PhD, traumatologist-orthopedist, head of Neurosurgery Department No. 3, Regional Clinical Hospital No. 1 n.a. Prof. SV Ochapovsky, Krasnodar, Russia;
Karapet Karapetovich Takhmazyan, traumatologist-orthopedist, head of Department of radiosurgical methods of diagnosis and treatment No. 2, Regional Clinical Hospital No. 1 n.a. Prof. SV Ochapovsky, Krasnodar, Russia;
Asker Alievich Afaunov, DMSc, traumatologist-orthopedist, Head of the Department of Orthopedics, Traumatology and Field Surgery, Kuban State Medical University, Krasnodar, Russia;
Dmitry Aleksandrovich Ptashnikov, DMSc, Prof., Russian Research Institute of Traumatology and Orthopedics n.a. RR Vreden, St. Petersburg, Russia;
Olga Nikolayevna Ponkina, MD, PhD, head of Anatomic pathology department, Regional Clinical Hospital No. 1 n.a. Prof. SV Ochapovsky, Krasnodar, Russia;
Nikolay Sviridovich Gavryushenko, PhD in Technics, head of the Testing Laboratory, Central Institute of Traumatology and Orthopaedics n.a. NN Priorov, Moscow, Russia.
Sergey Borisovich Malakhov, neurosurgeon, Neurosurgery department No. 3, Regional Clinical Hospital No. 1 n.a. Prof. SV Ochapovsky, Krasnodar, Russia;
Vladimir Konstantinovich Shapovalov, MD, traumatologist-orthopedist, Neurosurgery department No. 3, Regional Clinical Hospital No. 1 n.a. Prof. SV Ochapovsky, Krasnodar, Russia.