

The usage of percutaneous transpedicular osteosynthesis with kyphoplasty based on a finite-element experimental model of a spine fragment**A.N. Likholetov¹, D.S. Ivliev²**¹Republican Centre of Traumatology, Donetsk, Ukraine²Ural Clinical and Rehabilitation Centre Ltd., Nizhny Tagil, Russia

Objective Improve outcomes in patients treated for thoracolumbar spine injury based on updated methodological approaches to treatment tactics and analysis of stress-strain state (SSS) produced in a spinal fragment. Develop a technique for combined usage of percutaneous transpedicular spondylodesis and kyphoplasty for operative treatment of compression comminuted thoracolumbar spine injury being committed to minimally invasive technology. **Material and methods** Finite-element modeling (FEM) was performed to study SSS in an intact spinal motion segment with transpedicular stabilization in case of a traumatic injury to one vertebral body and also with combined application of transpedicular osteosynthesis and vertebroplasty in different loading regimes. **Results** Combined application of vertebroplasty and transpedicular fixation with metal systems has shown high efficacy with considerably decreased stress in intact vertebrae and decreased stress in the implanted metal construct. **Conclusions** The findings allowed for a new surgical technique developed by a concept of minimally invasive technology that is illustrated with a successful clinical instance.

Keywords: stress-strain state, finite-element modeling, percutaneous transpedicular osteosynthesis, vertebroplasty, kyphoplasty

A spinal injury is reported to account for 17.7 % of all skeletal injuries and is a devastating condition of locomotor apparatus that requires a continuous inpatient and rehabilitation treatment. Thoracic and lumbar fractures are most common making up 54.9 % of all spinal trauma cases [1, 2]. Various types of decompression stabilizing procedures, fixation spine systems, etc. are employed to address the condition [3]. Concise indications to operative treatment and a choice of an adequate intervention are to be considered for spine fractures. Vertebroplasty and kyphoplasty have gained wide acceptance worldwide. Percutaneous vertebroplasty is known to reshape an injured vertebra, prevent instability and compression progression, improve loading on the injured vertebra at an acute trauma [4–6]. However, possibilities and potential applications of vertebroplasty and kyphoplasty are not well established and further researches are needed with the techniques [4, 7]. Mathematical analysis and computer aided modeling of stress-strain state (SSS) of simulated spine are helpful in choosing stabilizing construct avoiding surgical intervention

[8–12]. The finite-element method is most common for building biometric model with sufficient approach to genuine anatomy of bone structures, various mechanical features and complicated specific loading system [8–10, 13, 14]. Current publications report studies of SSS of the spine fixed with different devices and no articles found on comparative analysis of fixation spine devices effecting SSS of the spine including the cases with vertebroplastic materials [8–10, 15, 16]. The question of minimally invasive technology is pressing to provide the clinical effect with minimal risk of complications. The factors served a stimulus for the present study.

Objective. Improve outcomes in patients treated for thoracolumbar spine injury based on updated methodological approaches to treatment tactics and analysis of stress-strain state (SSS) produced in a spinal fragment. Develop a technique for combined usage of percutaneous transpedicular spondylodesis and kyphoplasty for operative treatment of compression comminuted thoracolumbar spine injury being committed to minimally invasive technology.

MATERIAL AND METHODS

Biometric model was developed using mean values of L1–L3 vertebrae measured on CT scans of 27 male patients aged 30 to 40 years [10, 16]. Elastic elements with cross section being equidistant to that of the vertebral body were located between the neighboring vertebrae simulating intervertebral discs. Elastic prismatic elements simulating articular cartilage were used for calculations to be made between articular processes. Filamentous elastic elements were applied to simulate

posterior and anterior longitudinal ligaments, and flavum, interspinous and articular ligaments (Fig. 1a). Fractures were simulated (Fig. 1b) using technique of X.Y. Wang et al. [15]. Transpedicular fixation was produced with a construct comprising 7 mm fixation rod and two 5 mm transpedicular screws. The model shown in Fig. 1c was used to evaluate SSS in a spinal fragment with combined application of transpedicular osteosynthesis and vertebroplasty.

□ Likholetov A.N., Ivliev D.S. The usage of percutaneous transpedicular osteosynthesis with kyphoplasty based on a finite-element experimental model of a spine fragment. *Genij Ortopedii*. 2017. T. 23. No 2. pp. 187-194. DOI 10.18019/1028-4427-2017-23-2-187-194

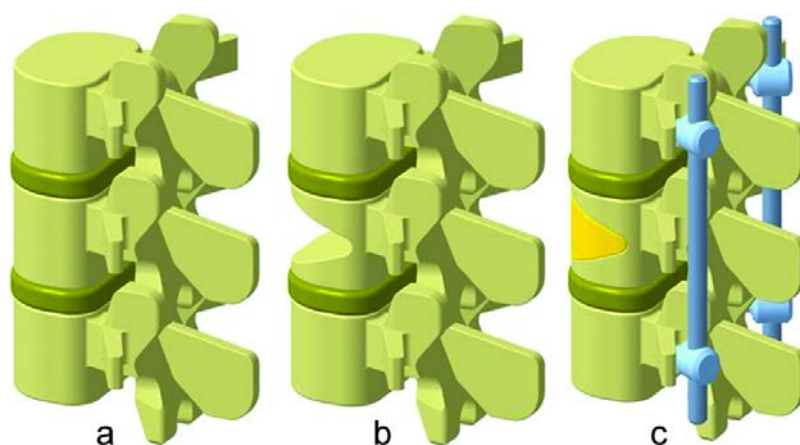


Fig. 1 Diagrams showing models used to measure SSS

All components of the finite-element (FE) model and the materials were accepted as homogenous and isotropic. Hooke's law was used as a material model. Publications on mechanical characteristics of biological tissues [8, 12, 17–19] indicate to considerable variations and wide ranges in values of interest. So, averaged values of mechanical characteristics were used for the FE spine model elements, implant and bone cement at simulation [10] that are presented in **Table 1**.

The loading used at simulation is one of the most important factors to determine SSS of the spine fragment of interest. Review of the literature indicated to considerable variations in the modes of load application used by the authors at FEM. The reported findings [11, 17–19] showed comparative analysis of theoretical and experimental values of vertebral SSS in a variety of load application presented in **Table 2**.

Table 1

Mechanical properties of material

Material	Young modulus, E (MPa)	Poisson's ratio, ν
Cortical bone	10 000	0.3
Cancellous bone	500	0.2
Articular cartilage	10	0.5
Intervertebral disc	5	0.5
Ligaments	20	0.3
Implant	110 000	0.3
Bone cement	3500	0.3

Table 2

Loads used for measurements with various body position

Body position	Force, H	Moment, Nm	Direction
Vertical position	500	0	–
Leaning forward	1200	10	forward
Leaning backwards	500	10	backwards

Therefore, experimental part of the study was based on literature review and our own findings.

The work reviews comprehensive examination and treatment of 50 patients with traumatic injuries of tho-

racic and lumbar spine who were observed and treated at the spinal department of DNIITO and neurosurgery department of the Republican Centre of Traumatology, Donetsk from 2005 to 2016. Inclusion criteria were applied to the cases of compression or comminuted compression fractures of the thoracolumbar spine AO types A2 and A3.

The study includes 36 (71.2 %) females and 14 (28.8 %) males. The patients' age ranged from 19 to 63 years.

Th₁₂ and L₁ vertebrae (40.5 %) were injured in most of the cases.

Spondylography in two views, SCT, MRI and standard neurological assessment were performed for all patients.

Philips MX-6000 Dual CT scanner was used for three-dimensional reconstruction at 1-mm step. MR imaging was performed at 1.5 T (General Electric 1,5T *Signa-Excite*).

All patients were divided into 2 groups according to the technique the patients were treated with. Index group included 18 patients who underwent the procedure we developed [10, 15, 16] employing less invasive technique with the CD Horizon® Sextant or Longitude system. All components of the system were implanted percutaneously. The technique of placing transpedicular screws is similar to that of a driving point to the vertebral body at vertebroplasty. Intubation general anaesthesia was used for construct placement. A needle, guide bar and screw were placed in the vertebral body through the arch root using posterior lateral approach after surgical site marking. With all screws in place they were connected by rods in pairs and fixed. *Ziem-Compact* C-Arm was used for radiological control of screw placement and vertebroplasty.

The results were compared with those of 32 control individuals with similar injuries who underwent open procedure of four-screw transpedicular construct placed in the intact vertebral bodies adjoining the injured body. Decompression was determined by neurological

symptoms MRI and SCT scans showed narrowing of the medullary canal and compression of the dural sac.

Vertebroplasty or kyphoplasty included a single-side transpedicular approach for compression fracture of the index group in addition to transpedicular fixation of vertebral bodies adjoining the injury at 50 % decrease of the original body height. Bilateral transpedicular puncture of the vertebral body with injected osteoinductive composite was produced for decreased body height of more than 50 % [10, 15, 16]. Kyphoplasty was performed for vertebral comminuted fractures using 15 mm *Kyphon Medtronic* balloon inflated with radiopaque fluid at pressure of 5 to 7 atm. Lateral radiological view was used to control balloon inflation.

Contact of the balloon wall and an arch lamina of the compressed vertebra served a sufficiency criterion. Then the resulting cavity was filled with composite. The manipulation was produced bilaterally at the same time. The priority of kyphoplasty with traumatic injury of vertebral body was supported by restored height of the involved vertebra and decreased risk of extravertebral efflux of bone cement due to peripheral compaction of bone tissue from inflated balloon [20]. Outcomes were evaluated with lateral radiological views using Cobb method and comparing changes in kyphotic angle of the involved vertebral segment of the index and control groups preoperatively, postoperatively and at 6-month follow-up.

RESULTS AND DISCUSSION

Figure 2 demonstrates results of SSS simulated for vertebral fracture and treated with transpedicular stabilization coupled with the usage of bone segment.

The findings indicated to decrease in the stress of both intact and the involved vertebra to the stress level of intact vertebrae. Such a conclusion could be made about stress intensity in the vertebral body depending on a torso position. A 2-to-3 fold increase was observed at leaning forward position as compared to the vertical torso position. Stress for vertebral bodies was shown to considerably decrease at leaning backwards due to the loading redistributed with the implant. In addition to that, substantial

decrease in the stress intensity in the vertebral arches, superior and inferior articular processes at any torso position due to redistributed load bearing. Analysis of stress intensity in the implant indicated to decrease in the stress of the posterior fixation rod by 2.5 times as compared with the previous simulation scenario and measures ~7 MPa for the vertical torso position, ~23 MPa for leaning forward and ~9 MPa for leaning backwards. The magnitude of stress imposed on the implant ranged depending on a torso position and measured ~0.42 MPa for the vertical position, ~1.21 MPa for leaning forward and ~0.37 MPa for leaning backwards.

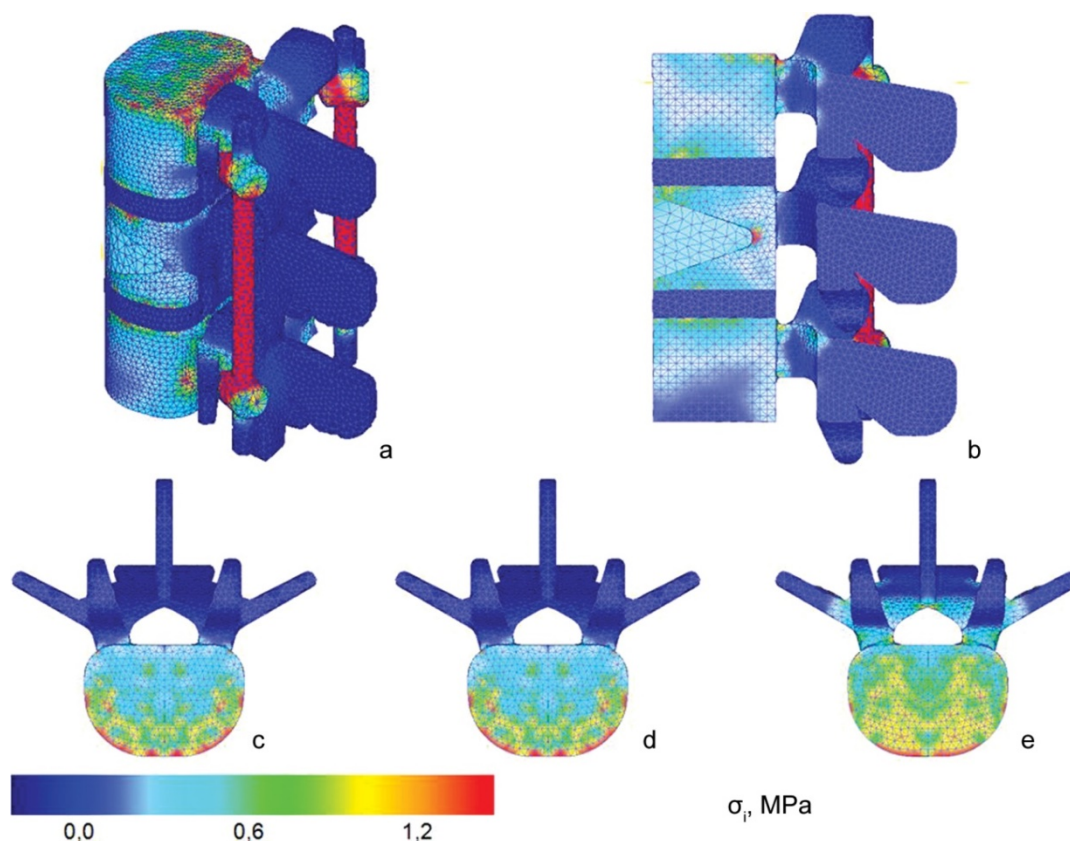


Fig. 2 Distribution of stress intensity in a vertebral fragment model at combination of transpedicular osteosynthesis and bone cement: a – isometry; b – cross section; c, d, e – top view of vertebrae when looking top-down

Comparative analysis of stress-strain state of the simulated spinal fragment injury using various surgical treatments revealed a higher level of reliable fixation with combined usage of transpedicular practice and bone cement as compared to the sole application of transpedicular fixation. It was manifested in considerably decreased stress in the intact vertebrae with attached screws and in the decreased stress in the metal construct used for fixation with impression defect of the vertebral body filled with composite.

All patients of the index group were encouraged to ambulate in the next 24 days following surgical intervention due to considerably decreased pain and absence of trauma to the soft tissues and improved supporting function of the posterior vertebral column.

The usage of transpedicular osteosynthesis and vertebroplasty appeared to be effective for stability of the correction achieved. Preoperative and postoperative measurements of kyphosis of the injured spinal fragment are presented in **Table 3**. An extent of the lost correction at 6 months and over was statistically less significant in the index group as compared with the control patients ($p < 0.05$).

The combined usage of vertebroplasty and transpedicular spinal stabilization was introduced into practice based on finite element models of the vertebral column [9, 11]. We report a clinical instance with per-

cutaneous minimally invasive technique used for the treatment.

Clinical instance. Male patient A., born 1958, inpatient medical records № 86403, was admitted to neurosurgical department of Regional Trauma Hospital with injury after a fall from the height of 2 m down the stairs. Radiographs and SCT scans showed unstable compression comminuted fracture of L1 vertebra with expressed compression of the right anterior superior and middle vertebral portions (**Fig. 3**). Neurological status indicated to evident pains, vertebrogenic, radicular syndrome.

The patient underwent operative intervention using the technique described. Skin incisions of 1/5 cm were used to place CD Horizon® Longitude percutaneous transpedicular screws in Th₁₂ and L₂ vertebral bodies, the rod mounted with an inserter was employed for distraction and extension to realign spinal canal (**Fig. 4**). Percutaneous transpedicular screws were placed in Th₁₂ and L₂ vertebral bodies on the right in a similar manner and cannula of *Kyphon* balloon kyphoplasty system was introduced into the body of injured L₁ vertebra through the right arch root under radiological control.

Then a balloon was guided through cannula and inflated with radiopaque solution under pressure that resulted in recovered configuration of the injured vertebral body. Then the balloon was deflated and removed (**Fig. 5**).

Table 3

Preoperative and postoperative measurements of kyphosis of the injured spinal fragment in index and control groups (degrees)

Group	Type of fracture	Preoperatively	Postoperatively		Loss of correction
			Radiological check-up	Radiological check-up at 6-month follow-up	
Index group (n = 18)	A2 (n = 8)	11.8 ± 8.6	1.7 ± 0.7	2.1 ± 0.8	0.4 ± 0.3
	A3 (n = 10)	16.9 ± 9.3	1.9 ± 0.9	2.4 ± 0.9	0.5 ± 0.2
Control group (n = 32)	A2 (n = 14)	12.2 ± 7.9	2.2 ± 0.6	6.7 ± 1.2*	4.5 ± 0.9*
	A3 (n = 18)	17.3 ± 8.9	2.7 ± 0.9	12.3 ± 2.1*	9.6 ± 1.7*

* – statistically significant differences (with $p < 0.05$) as compared to casualties with appropriate type of injury in the control group

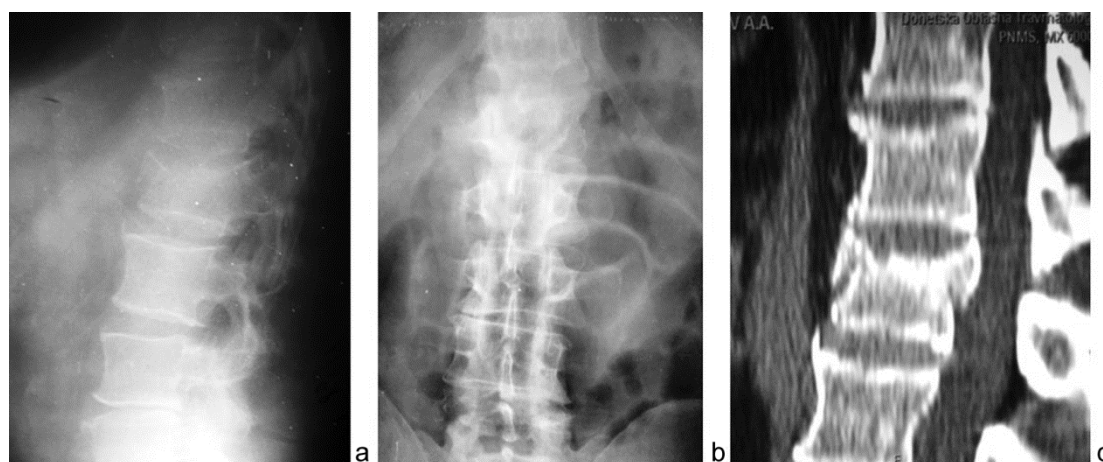


Fig. 3 Preoperative AP (b) and lateral (a) radiological views of lumbar spine of patient A. and SCT scan (c) of L1 vertebra

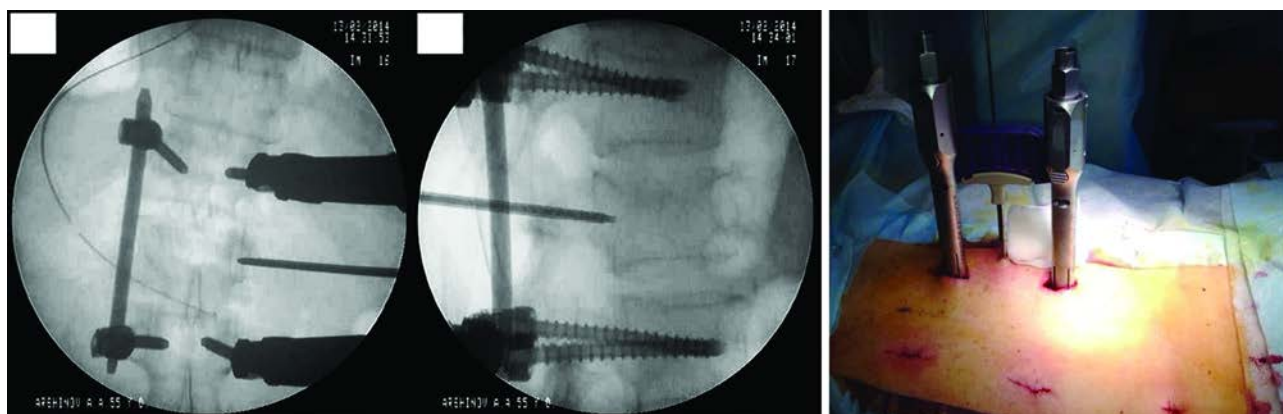


Fig. 4 Intraoperative photograph showing CD Horizon® Longitude percutaneous transpedicular screws placed bilaterally into Th₁₂ and L₂ vertebrae with the rod fixed on the left. Cannula of *Kyphon* balloon kyphoplasty system introduced into the body of L₁ vertebra on the right

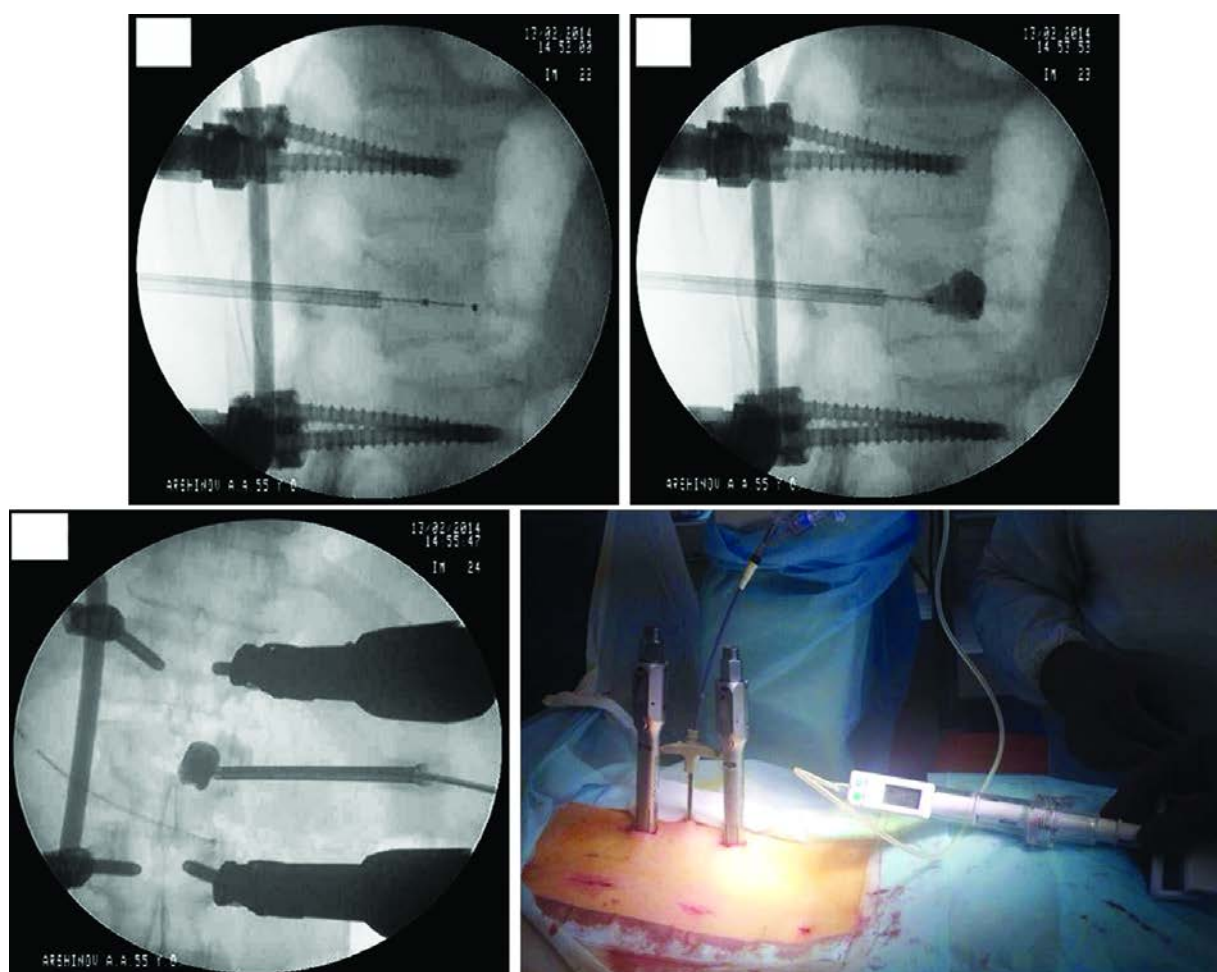


Fig. 5 Intraoperative photograph showing introduction of a balloon through cannula that was inflated with radiopaque solution under pressure

The resultant cavity was slowly filled with osteoinductive bone cement under radiological control (**Fig. 6**). Once an internal cast formed the system was removed and finally transpedicular system mounted.

Follow-up examination showed the stable fixation system with restored supportability of the vertebral column and considerably decreased compression of the spinal

canal (**Fig. 7**). Regress in the pain, radicular syndrome was observed on the next day after the surgery. No complications developed postoperatively. The patient could ambulate without bracing after 24 hours of the operative intervention and was discharged from the hospital in a satisfactory condition to be followed up by an orthopaedic and trauma surgeon at the place of residence.

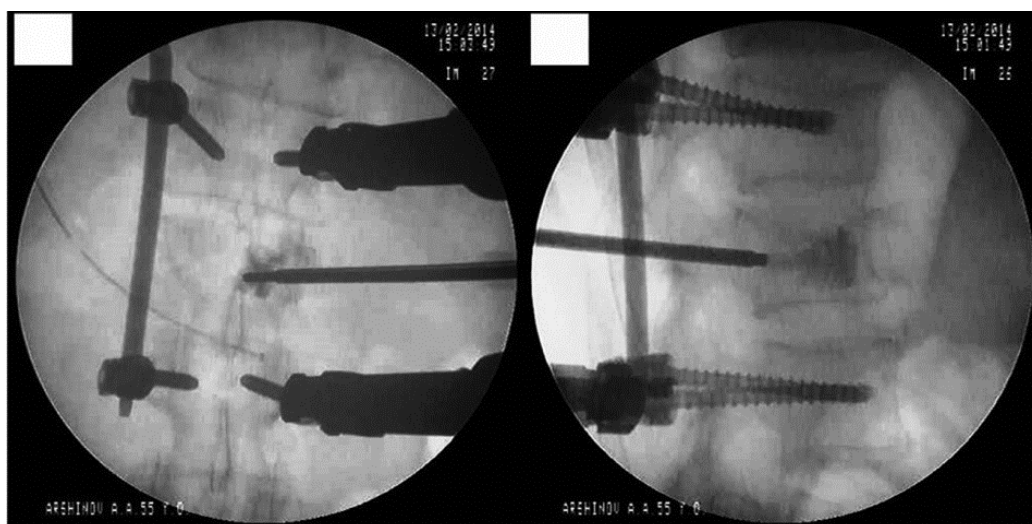


Fig. 6 Intraoperative photograph showing slow introduction of radiopaque osteoinductive bone cement into L_1 vertebral body

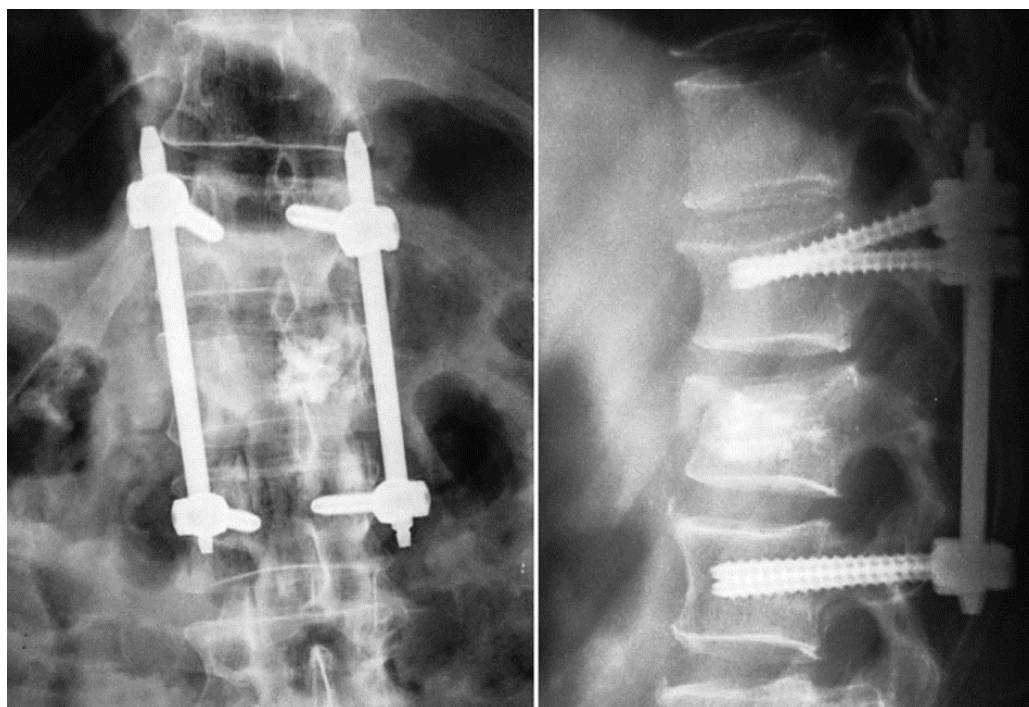


Fig. 7 Postoperative AP and lateral radiological views of lumbar spine showing the stable implanted system with restored supportability of the vertebral column

CONCLUSIONS

1. The combined usage of transpedicular osteosynthesis and vertebroplasty was shown to be the most efficient technique to relieve stress-strain state at the site of injury and adjacent segments used for mounting fixation screws and metal construct.

2. The sole application of transpedicular osteosynthesis of vertebrae adjacent to an injury resulted in enhanced stress-strain state at the transition site between the screw and the screw head that could be a potential fracture level.

3. A single approach was used for transpedicular stabilization of the spine and vertebroplasty with no

need of a combined approach and the technique can be applied for various types of injuries.

4. The operative intervention developed to employ a minimally invasive technique appeared to be the reliable and promising practice providing less intraoperative trauma to the soft tissues and blood loss, decrease in postoperative pains, early ambulation of the patients and shorter hospitalization length. The differentiated usage of minimally invasive stabilizing systems (Sextant, MANTIS) and puncture percutaneous vertebroplasty can improve outcomes of each specific case.

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Received: 10.05.2016

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