ISSN 0030-5987. Orthopaedics, traumatology and prosthetics. 2023. № 2

УДК 616.711-001.5-089.22:004.942](045)

DOI: http://dx.doi.org/10.15674/0030-59872023243-55

Mathematical modeling of variants of transpedicular fixation at the thoracolumbar junction after Th_{XII} vertebrectomy during trunk backward bending

O. S. Nekhlopochyn [1], V. V. Verbov [1], I. V. Cheshuk [1], M. Yu. Karpinsky [2], O. V. Yaresko [2]

[1] Romodanov Neurosurgery Institute, Kyiv, Ukraine

[2] Sytenko Institute of Spine and Joint Pathology National Academy of Medical Sciences of Ukraine, Kharkiv

Fractures at the thoracolumbar junction are the most common traumatic spinal injuries. Advances in instrumentation for vertebral body replacement have significantly improved surgical techniques. However, the biomechanical characteristics of stabilizing surgeries have been insufficiently studied. Objective. To investigate the stress-strain state (SSS) of a mathematical finite element model of the human thoracolumbar spine during trunk backward bending after Th_{XII} vertebra resection, considering different transpedicular fixation options. Methods. A mathematical finite element model of the human thoracolumbar spine — Th_{IX}–L_V vertebrae — was developed. The Th_{XII} vertebra was removed, and an interbody support and transpedicular system with 8 screws were implanted to simulate the post-surgical state after a Th_{XII} burst fracture with wide laminectomy, facetectomy, and corpectomy. The influence of transpedicular screw length and the presence of cross-links on the SSS of the model was examined. Results. The use of bicortical screws reduced stress levels in the bone elements of the model, except in the regions around the screws in the lumbar vertebrae, when compared to short screws. Installing cross-links decreased stress levels at all control points compared to models without cross-links. Specifically, in the presence of cross-links, the SSS values at the entry points of the short screws into the vertebral bodies of Th_X, Th_{XI}, L_I, and L_{II} were 2.3, 1.8, 1.2, and 5.0MPa, respectively, compared to 2.7, 2.0, 1.5, and 6.1 MPa in the models without cross-links. In the case of bicortical screws without cross-links, the stress values at the screw entry points into the pedicles of the corresponding vertebrae were 2.9, 1.5, 8.2, and 11.2 MPa, respectively, compared to 2.7, 1.5, 7.5, and 10.2 MPa in the models with cross-links. Conclusions. When the trunk is tilted backward, the use of cross-links reduces stress levels at all control points in the models, regardless of the screw length used. Bicortical transpedicular screws increase stress levels on the screws themselves and in the lumbar vertebral bodies surrounding them.

Переломи ділянки грудопоперекового переходу є найчастішими травматичними ураженнями хребта. Удосконалення систем стабілізації та конструкцій для заміни тіл хребців значно покращило техніку хірургічних утручань. Але особливості біомеханіки варіантів стабілізувальних операцій вивчені недостатньо. Мета. Вивчити напружено-деформований стан (НДС) моделі грудопоперекового відділу хребта під час нахилу тулуба назад після резекції хребця Th_{XII} за різних варіантів транспедикулярної фіксації. Методи. Розроблено математичну скінченно-елементну модель грудопоперекового відділу хребта людини — хребці Th_{IX}–L_V. Хребець Th_{XII} видалено і встановлено міжтілову опору та траспедикулярну систему із 8 гвинтів. Тобто, імітовано стан після хірургічного втручання з приводу вибухового перелому Th_{XII} із широкою ламінектомією, фасетектомією та корпектомією. Досліджували вплив на НДС моделі довжини транспедикулярних гвинтів і поперечних стяжок. Результати. Застосування бікортикальних гвинтів дозволило знизити рівень напружень у кісткових елементах моделі порівняно з короткими, за винятком зон навколо гвинтів у хребцях поперекового відділу. Установлення поперечних стяжок, порівняно з моделями без них, зменшило рівень напружень на всіх контрольних точках. Зокрема, за наявності стяжок показники НДС на рівні входу короткого гвинта в тіла хребців Th_X, Th_{XI}, L_I та L_{II} становили 2,3; 1,8; 1,2; 5,0 МПа відповідно проти 2,7; 2,0; 1,5; 6,1 МПа в моделі без стяжок. У разі введення бікортикальних гвинтів без стяжок у ділянках входу гвинта в ніжку дуги відповідних хребців напруження дорівнювали 2,9; 1,5; 8,2; 11,2 МПа проти 2,7; 1,5; 7,5; 10,2 МПа в моделі зі стяжками. Висновки. За умов нахилу тулуба назад використання поперечних стяжок дозволяє знизити рівень напружень у всіх контрольних точках моделей незалежно від довжини використаних гвинтів. Застосування бікортикальних транспедикулярних гвинтів призводить до підвищення рівня напружень на них та навколо в тілах хребців поперекового відділу хребта. Ключові слова. Скінченно-елементна модель, грудопоперековий перехід, корпоректомія, бікортикальна транспедикулярна стабілізація, поперечна стяжка, екстензія.

Key words. Finite element model, thoracolumbar junction, corpectomy, bicortical transpedicular stabilization, cross-link, extension

Introduction

Fractures of the thoracolumbar junction are the most frequent traumatic injuries of the spine, while burst fractures account for 21 to 30 % of all types of injuries in this area [1]. The goal of treatment of burst fractures is to decompress the spinal canal, restore the spinal axis by correcting the kyphotic deformity, and ensure the stability of this correction. In order to achieve the desired results in the absolute majority of cases, these injuries require surgical intervention [2, 3]. Currently, several different options for surgical correction have been developed, which are implemented from the back or front access, and combined options are also possible. At the same time, the issue of the advantages of one or another approach remains a subject of debate [4, 5]. Traditionally, during interventions from the posterior approach, adequate decompression is performed by laminectomy, if necessary, facetectomy and removal of bony fragments of the vertebral body, which compress the dural sac ventrally, and stabilization is implemented using transpedicular fixators. In the case of anterior or anterolateral approaches, a corpectomy is performed with decompression of the dural sac, replacement of the vertebral body with an autograft or a metal structure, followed by fixation of the bodies adjacent to the resected one with a plate or beams [6]. The biomechanical features of the outcomes of such operations have been sufficiently studied that, together with the documented complications in the early or remote postoperative periods, determines the search for more effective options for surgical interventions [7, 8].

The development of medicine in recent decades and the introduction into clinical practice of more advanced stabilization systems and structures for the replacement of vertebral bodies have made it possible to significantly optimize the technique of surgical interventions in the thoracolumbar region of the spine. Currently, performing a total corpectomy with installation of a vertebral body implant from a posterior approach and subsequent adequate dosage correction of the spine axis by installing a transpedicular system does not pose significant difficulties. At the same time, the specifics of the biomechanics of such surgical intervention have not been sufficiently studied. It should be noted that the currently debatable issue of long or short fixation in conditions of burst fractures of the thoracolumbar spine does not belong to surgical interventions with coprectomy [9]. In particular, taking into account that the installation of a structure to replace the vertebral body causes increased requirements for the stability of fixation, preferably only long (minimum 8-screw) stabilization is considered.

Lengthening the fixation system along with increasing reliability is known to be associated with a number of clinical and economic disadvantages. Therefore, the optimization of the technique can be achieved only by increasing the reliability without increasing the length. According to the literature, the main factors that affect the stability of the transpedicular system are the depth of insertion of the transpedicular screw and the presence of transverse ties, which, however, has certain characteristics for each type of intervention and requires further research [10–12].

Purpose: to study the stress-strain state of the model of the thoracolumbar section of the spine under the conditions of bending the trunk back after resection of the Th_{XII} vertebra and various options for transpedicular fixation.

Material and methods

A mathematical finite-element model of the human thoracolumbar spine with the Th_{IX}–L_{V} vertebrae was elaborated in the biomechanics laboratory of the State Institution Professor M. I. Sytenko Institute of Spine and Joint Pathology of the National Academy of Medical Sciences of Ukraine [13]. The Th_{IX} vertebra was removed, while elements of metal structures, such as an interbody support and a traspedicular system of 8 screws, were installed. That is, we simulated the condition after surgical intervention for a burst fracture of the Th_{IX} with wide laminectomy, facetectomy, and corpectomy (Fig. 1).

During the study, 4 variants of transpedicular fixation were modeled using short and long screws that pass through the cortical layer of the front surface of the vertebral body (bicortical insertion), as well as two transverse ties and without them (Fig. 2).

During modeling, the material was assumed to be homogeneous and isotropic. A 10-node tetrahedron with a quadratic approximation was chosen as a finite element. Mechanical properties of biological tissues (compact and cancellous bone tissue, intervertebral discs) and artificial materials for mathematical modeling were obtained from the literature (Table 1) [14–18]. The material of the structural elements was titanium. For the assessment, such characteristics as E — modulus of elasticity (Young's modulus), ν — Poisson's ratio were used.

The stress-strain state (SST) of the models was studied under the impact of a bending load, which acts from front to back and simulates the tilt of the body back. The load was applied to the body of the Th_{IX} vertebra and the articular surfaces of its spinous condyles. The load was 350 N, which corresponds to the weight of the upper body [19]. On the distal surface of the disc L, the model had a rigid fixation (Fig. 3).

For a convenient study of changes of SST in the models depending on the method of transpedicular fixation, the following control points were selected for recording stress values (Fig. 4):

1. The body of the Th_{IX} vertebra;
2. The body of the Th_{X} vertebra;
3. The body of the Th_{XI} vertebra;
4. Body of vertebra L_{I};
5. Body of vertebra L_{II};
6. The body of the L_{III} vertebra;
7. Body of vertebra L_{IV};
8. The body of the L_{V} vertebra;
9. The lower closing plate of the Th_{XI} body;
10. The upper locking plate of the L_{I} body;
11. Entry of the screw into the leg of the arch of the Th_{X} vertebra;
12. Entry of the screw into the leg of the arch of the Th_{XI} vertebra;
13. Entry of the screw into the leg of the arch of the L_{I} vertebra;
14. Entry of the screw into the leg of the L_{II} arch of the vertebra;
15. Th_{X} screws;
16. Th_{XI} screws;
17. L_{I} screws;
18. L_{II} screws;
19. Ties between screws in bodies Th_{X}–Th_{XI};
20. Ties between screws in bodies L_{I}–L_{II};
21. Interbody support.

The study of SST in the models was performed using the finite element method. The Mises stress [20] was used as a criterion for evaluating SST in the models. Modeling was performed with the help of the SolidWorks automated design system, SST

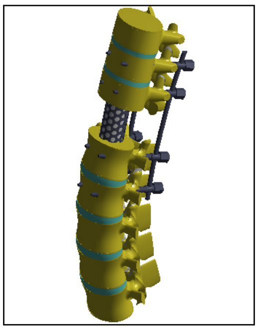

Fig. 1. Mathematical finite-element model of the thoracolumbar section of the human spine after removal of the Th_{IX} vertebra and installation of a vertebral body implant and stabilization system

Table 1

Mechanical characteristics of the materials used in the modeling process

Material	Young's modulus (E), MPa	Poisson's ratio, ν
Cortical bone	10 000	0.30
Spongy bone	450	0.20
Articular cartilage	10.5	0.49
Intervertebral discs	4.2	0.45
Titan BT-16	110 000	0.30

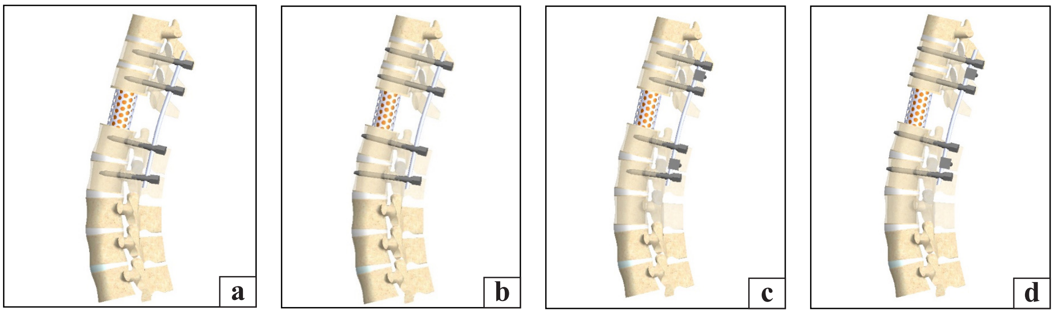

Fig. 2. Models with different options for transpedicular fixation: short (a) and long (b) screws without transverse ties; short (c) and long (d) screws with transverse ties

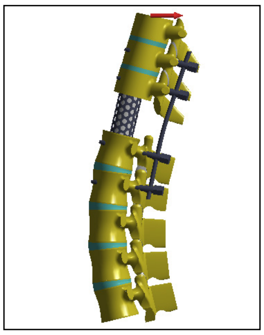

Fig. 3. Model loading scheme

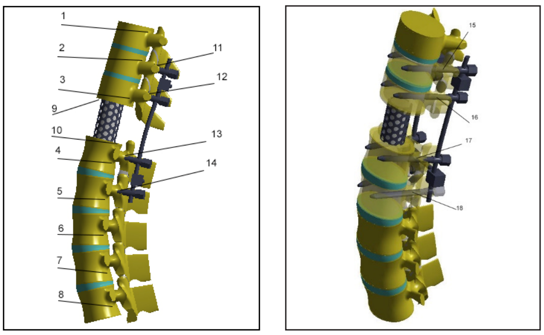

Fig. 4. Scheme of the location of control points

calculations of the models with the CosmosM software complex [21].

Results and their discussion

The first stage of the study was to assess the SST in the model of the thoracolumbar spine after resection of the Th_{XII} vertebra under the impact of the load that occurs when the trunk is tilted back. Transpedicular fixation with short screws without transverse ties was modeled. The stress distribution in the model is shown in Fig. 5.

The conducted studies showed that with the use of short screws without cross ties, maximum stresses of 16.5 MPa occur in the body of the L_{IV} vertebra when the body is tilted back. In the bodies of the L_I, L_{II}, L_V vertebrae, the stresses also become significant and are determined in the range from 12.5 to 13.4 MPa. Besides, a high level of stress was recorded in the places of contact of the vertebrae with the interbody support: L_I — 9.7 MPa, Th_{XI} — 8.3 MPa. Around the screws, the maximum stress occurred in the L_{II} vertebra — 6.1 MPa, in the others the figure did not exceed the limit of 2.7 MPa. Among the fixing screws, the one located in the L_I vertebra was the most stressed (30.1 MPa), and the least in the L_{II} vertebra (9.4 MPa). The stresses on the screws in the thoracic vertebrae were distributed almost uniformly in the range from 14.6 to 15.3 MPa; in the interbody support they were determined at the level of 45.1 MPa (Table 2).

Figure 6 shows the SST model of the thoracolumbar section of the spine after resection of the Th_{XII} vertebra under the impact of the load that occurs when the trunk is tilted back (transpedicular fixation with long screws without transverse ties).

Replacing short fixing screws with long ones under the conditions of tilting the trunk back led to minor changes in the stress level in the bone structures, mainly in the downward direction. A slight increase in the stress level by an average of 0.2 MPa was determined in the bodies of L_{II}–L_V vertebrae. A greater increase was recorded around the screws located in the lumbar vertebrae: L_I — up to 8.2 MPa, L_{III} — up to 11.2 MPa. In all elements of the metal structure,

Table 2

Values of stresses in models of the thoracolumbar spine after resection of the Th_{XII} vertebra under the impact of the load that occurs during the tilt of the trunk back, with different options for transpedicular fixation

Control point			Stress, MPa			
No.	area		without ties		with ties	
			short screw	long screw	short screw	long screw
1	bone tissue	body of the vertebra Th_{IX}	1.4	1.4	1.4	1.4
2		body of the vertebra Th_X	5.6	4.9	5.5	4.5
3		body of the vertebra Th_{XI}	5.0	4.6	4.7	4.2
4		body of the vertebra L_I	6.8	6.3	6.5	6.0
5		body of the vertebra L_{II}	12.5	12.7	11.5	11.4
6		body of the vertebra L_{III}	13.3	13.4	12.3	12.4
7		body of the vertebra L_{IV}	16.5	16.9	16.2	16.6
8		body of the vertebra L_V	13.4	13.8	12.9	13.0
9		lower body locking plateTh_{XI}	8.3	8.2	8.0	6.4
10		upper body locking plate L_I	9.7	9.3	8.4	7.7
11		screw entry Th_X	2.7	2.9	2.3	2.7
12		screw entry Th_{XI}	2.0	1.5	1.8	1.5
13		screw entry L_I	1.5	8.2	1.2	7.5
14		screw entry L_{II}	6.1	11.2	5.0	10.2
15	metal construction	screws Th_X	15.3	18.3	14.5	16.1
16		screws Th_{XI}	14.6	19.6	13.6	18.4
17		screws L_I	9.4	16.8	7.1	16.4
18		screws L_{II}	30.1	38.2	27.1	33.3
19		ties Th_X–Th_{XI}	—	—	2.8	2.3
20		ties L_I–L_{II}	—	—	5.8	6.3
21		interbody support	45.1	46.0	40.2	40. 3

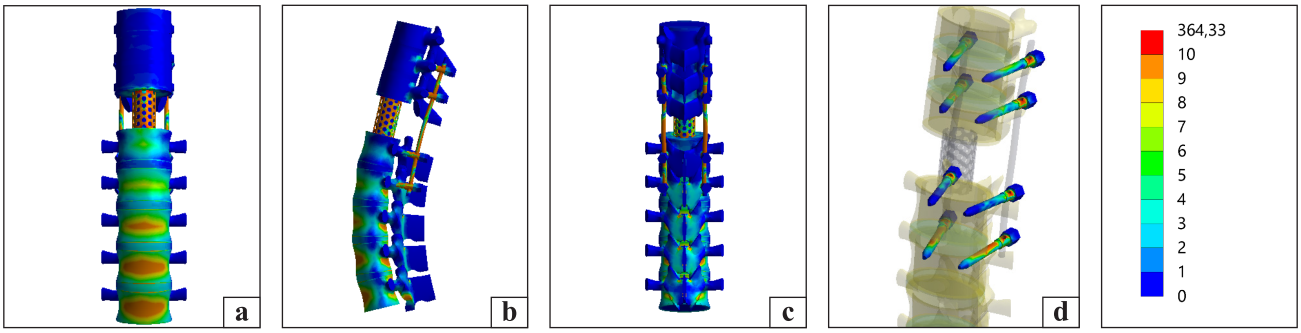

Fig. 5. The pattern of stress distribution in the model of the thoracolumbar spine after resection of the Th_{XII} vertebra under the impact of the load that occurs when the trunk is tilted back. Transpedicular fixation with short screws without transverse ties: front (a), side (b) and back (c) views; screws (d)

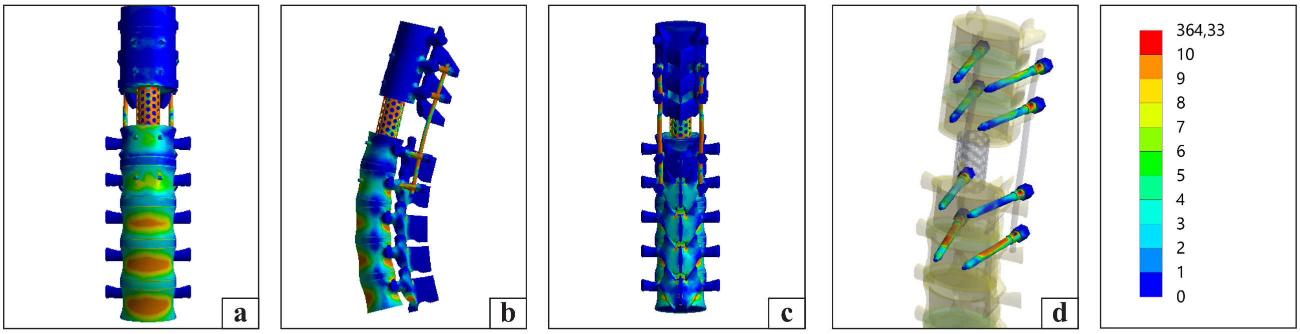

Fig. 6. Stress distribution in the model of the thoracolumbar spine after resection of the Th_{XII} vertebra under the impact of the load that occurs when the trunk is tilted back. Transpedicular fixation with long screws without cross ties: front (a), side (b) and back (c) views; screws (d)

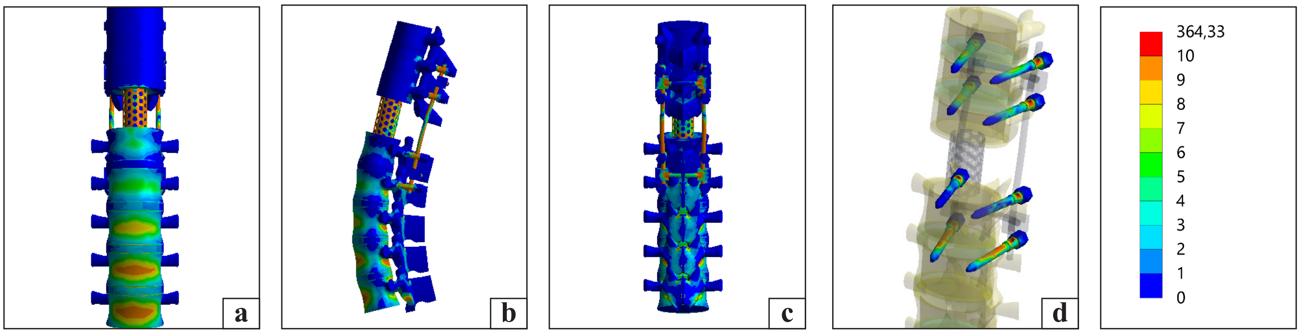

Fig. 7. Stress distribution in the model of the thoracolumbar spine after resection of the Th_{XII} vertebra under the impact of the load that occurs when the trunk is tilted back. Transpedicular fixation with short screws with transverse ties: front (a), side (b) and back (c) views; screws (d)

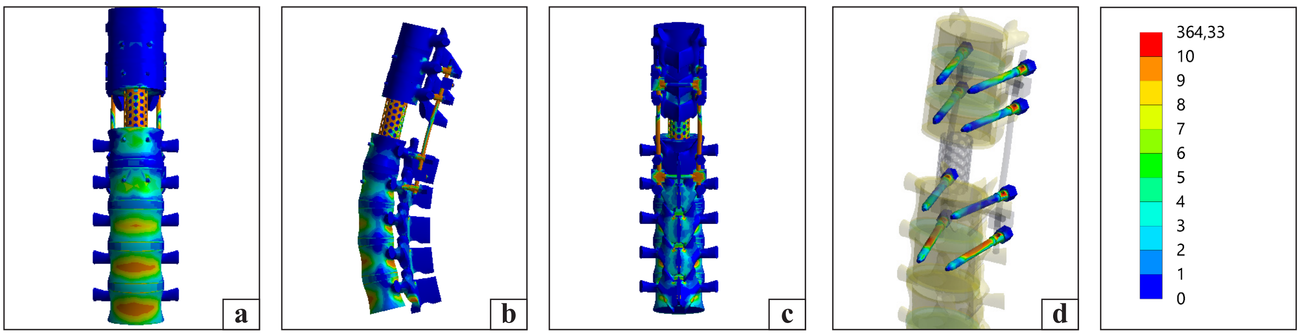

Fig. 8. Stress distribution in the model of the thoracolumbar spine after resection of the Th_{XII} vertebra under the impact of the load that occurs when the trunk is tilted back. Transpedicular fixation with short and long transverse ties: front (a), side (b) and back (c) views; screws (d)

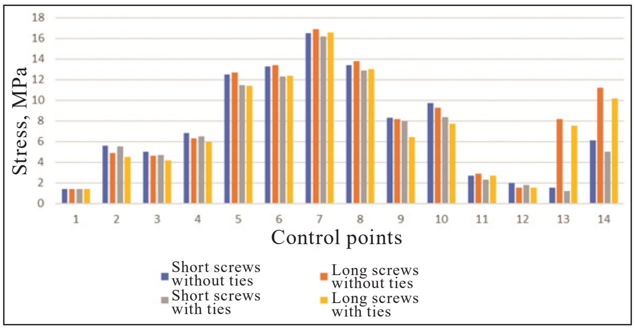

Fig. 9. Diagram of stress values at control points on the bone elements of the models

the level of stress increased: the most on the screw in the L_I vertebra (up to 16.8 MPa), slightly in the interbody support (up to 46.0 MPa) (Table 2).

The pattern of stress distribution in the model of the thoracolumbar spine after resection of the Th_{XII} vertebra under the impact of the load that occurs when the trunk is tilted back (transpedicular fixation with short screws with transverse ties) is shown in Fig. 7. It can be seen that the use of transverse ties made it possible to reduce the stress level at all control points of the model (Table 2). The magnitudes of stress on the tie-rods were determined at the level of 2.8 and 5.8 MPa in the thoracic and lumbar regions, respectively.

The last stage of the study involved evaluation of the effect of transverse ties in the case of using long fixing screws on the distribution of stresses in the model under the conditions of tilting the body back (Fig. 8). It has been proven that there are no significant changes in SST in this case compared to the model with long screws without ties, but all changes are aimed at reducing the amount of stress (Table 2).

The diagram (Fig. 9) clearly shows that the values of stresses in the bone elements of the models for all variants of transpedicular fixation of the thoracolumbar spine under the impact of the load that occurred during the bending of the trunk back do not differ significantly. The general trend can be characterized as follows: the use of long screws makes it possible to reduce the stress level in the bony elements of the model compared to short ones, except for the area around them in the lumbar vertebrae. At the same time, an increase in the stress level is established on the long screws.

Cross ties reduce the stress level at all control points of the model compared to models without ties.

In order to assess general pattern of biomechanics of the fixed thoracolumbar spine and determine the optimal stabilization technique, the results obtained in this study should be interpreted in terms of their clinical significance in comparison with the results of studies of other loading patterns.

Conclusions

Under the conditions of tilting the body back, the use of transverse ties allows to reduce the stress level at all control points of the models, regardless of the length of the used fixing screws.

An increase in the length of the fixation screws results in an increase in the level of stress on them and, as a result, in the bodies of the vertebrae of the lumbar spine around these screws, which has an absolute clinical significance.

Conflict of interest. The authors declare no conflict of interest.

References

1. Katsuura, Y., Osborn, J. M., & Cason, G. W. (2016). The epidemiology of thoracolumbar trauma: A meta-analysis. *Journal of orthopaedics, 13*(4), 383–388. https://doi.org/10.1016/j.jor.2016.06.019
2. Tanasansomboon, T., Kittipibul, T., Limthongkul, W., Yingsakmongkol, W., Kotheeranurak, V., & Singhatanadgige, W. (2022). Thoracolumbar burst fracture without neurological deficit: review of controversies and current evidence of treatment. *World neurosurgery, 162*, 29–35. https://doi.org/10.1016/j.wneu.2022.03.061
3. Popsuishapka, K. O. (2018). *Treatment of the thoracic and lumbar spine vertebrae fractures (clinical and experimental justification)* [Doctoral thesis, Sytenko Institute of Spine and Joint Pathology NAMS of Ukraine, Kharkiv] https://sytenko.org.ua/scientific-activity/thesis. (in Ukrainian)
4. Dai, L. Y., Jiang, L. S., & Jiang, S. D. (2009). Anterior-only stabilization using plating with bone structural autograft versus titanium mesh cages for two- or three-column thoracolumbar burst fractures: a prospective randomized study. *Spine, 34*(14), 1429–1435. https://doi.org/10.1097/BRS.0b013e3181a4e667
5. Xu, G. J., Li, Z. J., Ma, J. X., Zhang, T., Fu, X., & Ma, X. L. (2013). Anterior versus posterior approach for treatment of thoracolumbar burst fractures: a meta-analysis. *European spine journal, 22*(10), 2176–2183. https://doi.org/10.1007/s00586-013-2987-y
6. Dai, L. Y., Jiang, S. D., Wang, X. Y., & Jiang, L. S. (2007). A review of the management of thoracolumbar burst fractures. *Surgical neurology, 67*(3), 221–231. https://doi.org/10.1016/j.surneu.2006.08.081
7. Kaneda, K., Taneichi, H., Abumi, K., Hashimoto, T., Satoh, S., & Fujiya, M. (1997). Anterior decompression and stabilization with the Kaneda device for thoracolumbar burst fractures associated with neurological deficits. *The Journal of bone and joint surgery. American volume, 79*(1), 69–83. https://doi.org/10.2106/00004623-199701000-00008
8. Galbusera, F., Volkheimer, D., Reitmaier, S., Berger-Roscher, N., Kienle, A., & Wilke, H. J. (2015). Pedicle screw loosening: a clinically relevant complication? *European spine journal, 24*(5), 1005–1016. https://doi.org/10.1007/s00586-015-3768-6
9. Wong, C. E., Hu, H. T., Tsai, C. H., Li, J. L., Hsieh, C. C., & Huang, K. Y. (2021). Comparison of Posterior Fixation Strategies for Thoracolumbar Burst Fracture: A Finite Element Study. *Journal of biomechanical engineering, 143*(7), 071007. https://doi.org/10.1115/1.4050537
10. Liu, J., Yang, S., Lu, J., Fu, D., Liu, X., & Shang, D. (2018).

Biomechanical effects of USS fixation with different screw insertion depths on the vertebrae stiffness and screw stress for the treatment of the L1 fracture. *Journal of back and musculoskeletal rehabilitation, 31*(2), 285–297. https://doi.org/10.3233/BMR-169692
11. Cornaz, F., Widmer, J., Snedeker, J. G., Spirig, J. M., & Farshad, M. (2021). Cross-links in posterior pedicle screw-rod instrumentation of the spine: a systematic review on mechanical, biomechanical, numerical and clinical studies. *European spine journal, 30*(1), 34–49. https://doi.org/10.1007/s00586-020-06597-z
12. Karami, K. J., Buckenmeyer, L. E., Kiapour, A. M., Kelkar, P. S., Goel, V. K., Demetropoulos, C. K., & Soo, T. M. (2015). Biomechanical evaluation of the pedicle screw insertion depth effect on screw stability under cyclic loading and subsequent pullout. *Journal of spinal disorders & techniques, 28*(3), E133–E139. https://doi.org/10.1097/BSD.0000000000000178
13. Nekhlopochyn, O. S., Verbov, V. V., Karpinsky, M. Y., & Yaresko, O. V. (2021). Biomechanical evaluation of the pedicle screw insertion depth and role of cross-link in thoracolumbar junction fracture surgery: a finite element study under compressive loads. *Ukrainian Neurosurgical Journal, 27*(3), 25–32. https://doi.org/10.25305/unj.230621
14. Cowin, S. C. (2001). *Bone Mechanics Handbook*. Boca Raton: CRC Press.
15. Boccaccio, A., & Pappalettere, C. (2011) Mechanobiology of fracture healing: basic principles and applications in orthodontics and orthopaedics. In V. Klika (Ed.), *Theoretical Biomechanics* (pp. 21–48). Rijeka, Croatia.
16. Nekhlopochin, A. S., Nekhlopochin, S. N., Karpinsky, M. Yu., Shvets, A. I., Karpinskaya, E. D., & Yaresko, A. V. (2017). Mathematical analysis and optimization of design characteristics of stabilizing vertebral body replacing systems for subaxial cervical fusion using the finite element method. *Hirurgiâ pozvonocnika, 14*(1), 37–45. https://doi.org/10.14531/ss2017.1.37-45
17. Radchenko, V., Kutsenko, V., Popov, A., Karpinsky M., & Karpinska, O. (2022). Modeling the variants of transpedicular fixation of the thoracic spine in the rejection of one-three vertebrae. *Trauma, 18*(5), 95–102. https://doi.org/10.22141/1608-1706.5.18.2017.114125 (in Ukrainian)
18. Niinomi, M. (2008). Mechanical biocompatibilities of titanium alloys for biomedical applications. *Journal of the mechanical behavior of biomedical materials, 1*(1), 30–42. https://doi.org/10.1016/j.jmbbm.2007.07.001
19. Krishnan, R. H., Devanandh, V, Brahma, A. K, & Pugazhenthi, S. Estimation of mass moment of inertia of human body, when bending forward, for the design of a self-transfer robotic facility. *Journal of Engineering Science and Technology, 11*(2), 166 – 176.
20. Rao, S. S. (2010). *The finite element method in engineering* (5^{th} ed). Editeur: Elsevier Science.
21. Kumar, K, Zindani, D, & Davim. J. P. (2020). Mastering SolidWorks. *Practical Examples*. Springer Cham. https://doi.org/10.1007/978-3-030-38901-7

The article has been sent to the editors 14.04.2023

MATHEMATICAL MODELING OF VARIANTS OF TRANSPEDICULAR FIXATION AT THE THORACOLUMBAR JUNCTION AFTER TH_{XII} VERTEBRECTOMY DURING TRUNK BACKWARD BENDING

O. S. Nekhlopochyn [1], V. V. Verbov [1], I. V. Cheshuk [1], M. Yu. Karpinsky [2], O. V. Yaresko [2]

[1] Romodanov Neurosurgery Institute, Kyiv, Ukraine
[2] Sytenko Institute of Spine and Joint Pathology National Academy of Medical Sciences of Ukraine, Kharkiv

✉ Oleksii Nekhlopochyn, MD, PhD: AlexeyNS@gmail.com
✉ Vadim Verbov, MD, PhD: v.verbov@gmail.com
✉ Ievgen Cheshuk, MD: evcheshuk@gmail.com
✉ Mykhailo Karpinsky: korab.karpinsky9@gmail.com
✉ Olexander Yaresko: avyresko@gmail.com