

Impact of injury on changes in biomechanical loads in human lumbar spine

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Implementation of new spine stabilisation systems should be preceded by the analysis of the behaviour of healthy and damaged spine under laboratory conditions. Research was performed on two-part and three-part segments without damage and with disc damage in the two-part segment, and with a wedge cut in the vertebra in the three-part segment. In the two-part segment, a relative power necessary for inducing extension–compression in the damaged segment is twice as high as in the damaged three-part segment. In the damaged two-part segment, the motion in the sagittal plane needs a relative power being more than twice as high as in the damaged three-part segment. Yet absolute average values of powers examined in the two-part and three-part segment systems in the undamaged spine for all types of motion were similar, with slight advantage of the two-part segment system. Basic two-part segment of the spine motion system is its most stable functional part.

Key words: biomechanics, stability, lumbar spine, spine injury, humans

1. Introduction

Since the introduction of transpedicular screws their application in clinical practice has become very popular both in mono- and multilevel spine fixations [1], [2]. The construction of new spine stabilisation systems requires an appropriate selection of construction characteristics of transpedicular implants, preceded by the reliable analysis of the behaviours of healthy human spine, or at least animal spine, similar in terms of biomechanics to human spine [3].

In many papers, the analysis of the stability of intact and injured spine was performed on the basis of the stereometric measurements of the shift of motion segments under the constant load of 5 or 10 Nm [4]–[7]. Simultaneously it is emphasized that the research on its behaviour should be conducted at least with load for the movement of extension–compression and bending in the frontal plane and sagittal plane. At

the same time, the changes identified in those behaviours referring to the injured spine indicate the reason for its surgical stabilisation and for research on new types of spinal implants and their application in clinical practice.

The main goal of our study was to analyse the distribution of loads in the intact and injured “in vitro” two-part and three-part segments of spine at a constant value of shift in each of the 3 basic directions of spine motion. Identification of those loads should be useful in a right choice of the construction characteristic of new implants, which have to restore normal spine stability in future research.

2. Material and methods

In accordance with the consent given by the Bioethical Commission, four cadaveric human spines

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were used for research which covered the Th 11 to S1 sections. In three cases, anatomic specimens were taken from men, and in one case – from a woman. Age average of the dead persons amounted to 43.5 years and ranged between 40 and 50. After having taken the specimens, muscles were removed, and the uninjured ligament and capsule system as well as intervertebral disc were retained. Then the prepared spine specimen was subject both to radiological examination, in order to exclude spine diseases, and to densitometric examination by means of Lunar-Expert device to specify bone mineral density (BMD). Spine specimens were not taken from victims of accidents because the spine might have been damaged in these traumatic cases. Following these diagnostic procedures, the specimens were frozen at $-22\text{ }^{\circ}\text{C}$ in double plastic bag. 24 hours prior to the examination the specimens were defrosted at $+4\text{ }^{\circ}\text{C}$, and the last hour at room temperature. Throughout the whole examination on the examination post the specimens were moistened with saline solution. This procedure does not change biomechanical characteristics of the specimens [8], [9].

The spines were subject to unsymmetrical shift of $+3/-4\text{ mm}$ for extension–compression and to symmetrical shift for bending, in the frontal plane ($+0.14/-0.14\text{ rad}$) and in the sagittal plane ($+0.11/-0.11\text{ rad}$), respectively.

The research was performed for the lumbar sections of the spine in two-part and three-part segments without damage and with disc damage to the two-part segment and with a wedge cut in the frontal part of the vertebra, with ligamentotaxis, for the three-part segment.

Spines were fixed on a specially designed examination post, whose design was registered as two models, 114484 and 114485 [10].

Then the examination post together with the spine under examination were fixed on handgrips of 8501 Instron resistance machine. Two rods crossing at 90 degrees were carried through vertebra L3 – the first in the median axis through the centre of the vertebra, the second crosswise, near the posterior wall of the vertebra body (figure 1). In the first stage, the vertebra L5 was fixed on the testing device and the motor segment L4/L5 was subject to examination, i.e.:

- uninjured,
- with discectomy of L4 to achieve instability.

In the second stage, the vertebra Th12 was fixed on the testing device and the section Th12–L2 was evaluated by loading the rods carried through L3 body analogically to the one described above. We analyzed:

- uninjured spine,
- spine with produced “fracture” of L1 by means of a wedge cut of the height of $1/2$ of the body turned



Fig. 1. Testing spine fixed on spine tester

frontward with the retention of anterior longitudinal ligament in order to recreate ligamentotaxis.

Protruding rod ends located 70.3 mm from the centre of the vertebra were shifted $\pm 10\text{ mm}$ with a speed of 0.3 mm/s in the frontal plane working on the left side of the protruding rod, thus having a bend of 0.14 rad leftwards at loading, and rightwards at extension. In the sagittal plane, the frontal part of the protruding rod was loaded and unloaded, thus obtaining a shift of $\pm 7\text{ mm}$ within 62.4 mm. It corresponded to the bending degree of 0.11 rad. While stabilizing both rods in four points (right–left–front–back) 4-mm compression shifts and 3-mm extension shifts took place in all cases. For this movement the speed of displacement was 0.15 mm/s. The third cycle of loading/unloading was subject to analysis.

All research procedures were carried out in accordance with the guidelines given by WILKE [11] in order to standardise the stability of spinal implants for in vitro research.

3. Results

The research on loads in compression–extension shows that in the two-segment system an average range of relative strength necessary to induce 4-mm compres-

sion and 3-mm extension in the injured segment is twice as high as in similar shifts in the injured three-segment system (figure 2).

Similar measurements of the moments of strength for motion in the sagittal plane, thus flexion and extension, in accordance with the research methodology revealed that also for that motion an average range of

relative strength in the injured two-segment system was more than twice as large as that in the injured three-segment system (figure 3).

Only the moments of strength occurring in motion in the frontal plane for the injured two- and three-segment systems did not show any significant differences (figure 4).

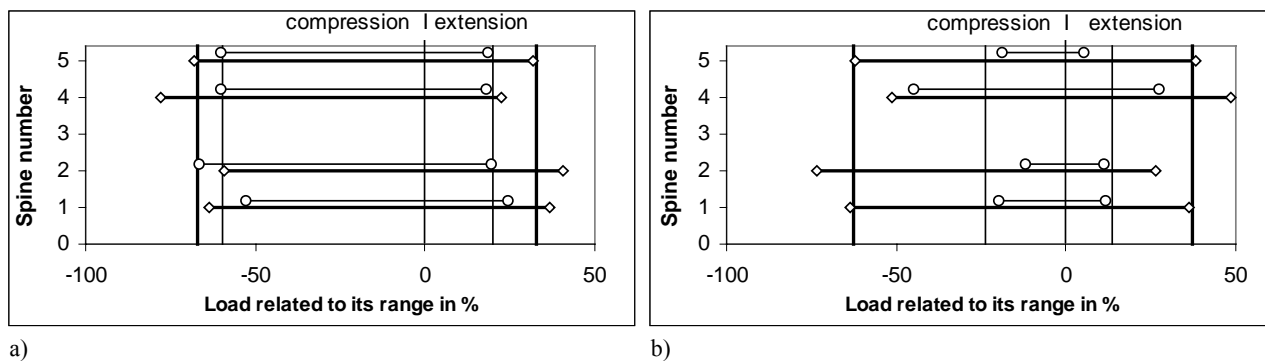


Fig. 2. Range of load changes taking account of their symmetry or asymmetry for compression–extension in two-segment system (a) and three-segment system (b). Thick lines represent uninjured spines, and thin lines – injured spines. Vertical lines indicate average strength ranges. In all cases, load values are relative and refer to load values of uninjured spines. Thus, for uninjured spines this range is always 100%

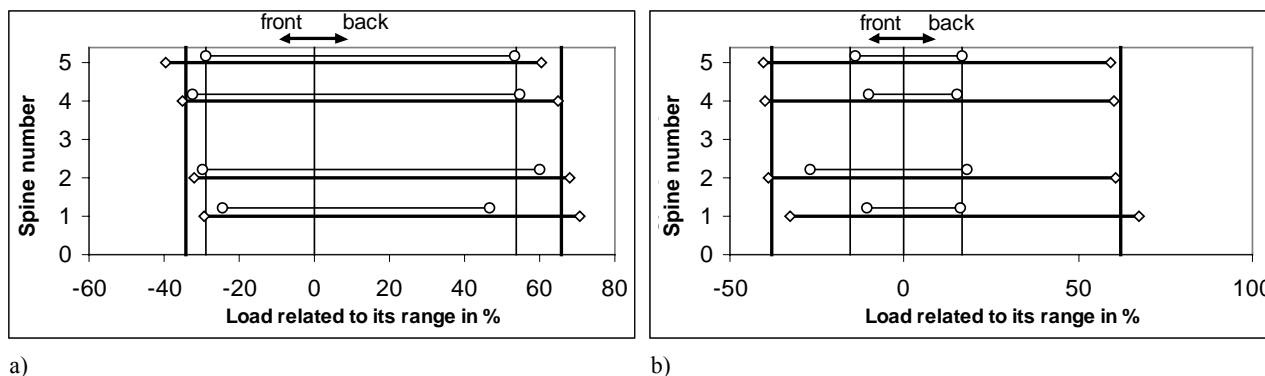


Fig. 3. Range of load changes taking account of their symmetry or asymmetry for motions in the sagittal plane in two-segment system (a) and three-segment system (b)

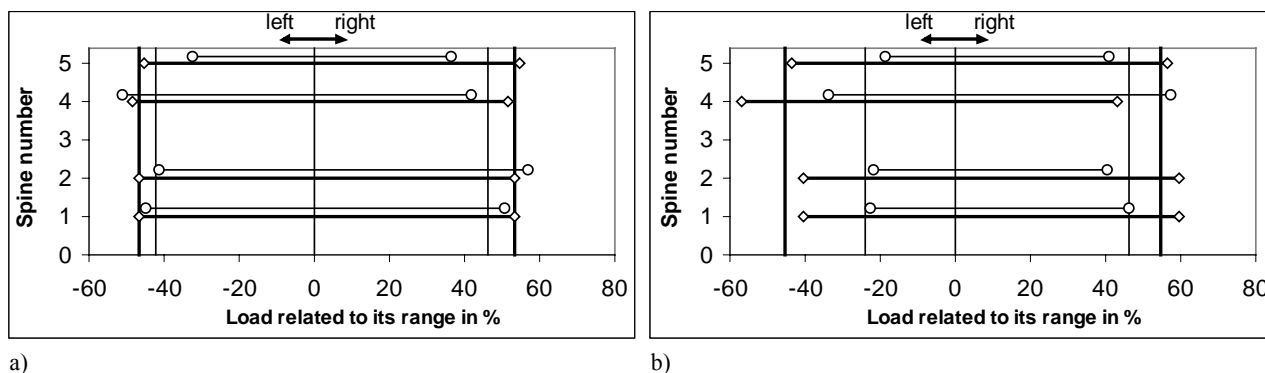


Fig. 4. Range of load changes taking account of their symmetry or asymmetry for motions in the frontal plane in the two-segment system (a) and three-segment system (b)

Table 1. Average differences in relative changes in load reductions in the two- and three-segment systems for uninjured spines

Type of system examined	Compression–extension		Bending			
			Front–back		Left–right	
Two-segment	11%	37%	17%	18%	8%	13%
Three-segment	63%	64%	60%	73%	46%	14%

Table 2. Average values of loads in the two- and three-segment systems in the uninjured and injured spines for all the types of motion

Type of system examined	Type of movement	Type of spine examined	S1	S2	S3	S4	Average
Two-segment	Compression–extension, strength in N	Uninj.	1147.20	1176.36	1120.40	1086.62	1132.65
		Inj.	883.77	1010.96	873.91	857.17	906.45
	Motion in the sagittal plane, moment in Nm	Uninj.	26.40	27.53	24.70	31.26	27.47
		Inj.	18.70	24.75	21.54	25.70	22.67
	Motion in the frontal plane, moment in Nm	Uninj.	15.98	14.61	11.12	16.02	14.43
		Inj.	15.24	14.34	10.33	11.02	12.73
Three-segment	Compression–extension, strength in N	Uninj.	1345.23	782.90	604.07	1016.87	937.27
		Inj.	424.56	180.63	434.27	244.54	321.00
	Motion in the sagittal plane, moment in Nm	Uninj.	25.04	14.65	15.70	15.67	17.77
		Inj.	6.62	6.58	3.96	4.83	5.50
	Motion in the frontal plane, moment in Nm	Uninj.	16.67	13.17	12.15	11.75	13.44
		Inj.	11.43	8.20	11.06	7.00	9.42

Inj. – injured, uninj. – uninjured.

Table 3. The results of statistical tests for the equality of variances and equal means for strength values in all systems in the uninjured and injured spines for all types of motion

Type of movement	Segments	Test for equality of variances			Test for equal means		
		F	F_{cr}	Result	t	T_{cr}	Result
Compression–extension	2	0.29	9.29	positive	5.64	2.45	negative
	3	6.26		positive	3.57		negative
Frontal plane	2	1.07		positive	1.55		positive
	3	0.91		positive	2.58		negative
Sagittal plane	2	0.78		positive	1.81		positive
	3	13.56		negative	4.86		negative

F – Snedecor's F distribution test, t – Student's t -test, $p \leq 0.05$

Positive results of both tests mean the possibility of accepting the null hypothesis whose variances and means in the uninjured and injured spines are equal.

In all the cases, the load values presented are relative and refer to load values of uninjured spines. Thus, for uninjured spines this range is always 100%.

In the case of examining three-segment system, the differences in loads or bending moments for in-

jured and uninjured spines are considerably greater than those for two-segment system. Average load changes following injury are given in table 1.

However, absolute average values of the loads tested in the two- and three-segment systems in the

uninjured spine for all types of motion were similar, with a slight prevalence of load values necessary for performing motion in the range examined in the two-segment system (see table 2).

The results of statistical tests for the equality of variances and equal means for the strength values in both systems in the uninjured and injured spines for all the types of motion are shown in table 3.

4. Discussion

Both vertebral bodies and intervertebral discs are of the vital importance in shifting strengths affecting the spine. Biomechanical research conducted by YAGANANDAN et al. [12] showed that ca. 80% of compression loads affecting the spine in the vertical position is shifted via bodies of lumbar vertebrae simultaneously with the intervertebral disc, of which 40% resistance is connected with the cortex layer of the vertebral body. The remaining nearly 20% of compression loads shifted by the spine fall on intervertebral joints [13]. However, this value can increase to 70% in the case of narrowing the intervertebral disc due to degenerative changes [11], thus the reduction of its resistance to active compression load. In our material, this is evidenced by the reduction of average load necessary to induce the intended motion in the two-segment system with an injured intervertebral disc. Artificially induced injury to the vertebral body in the three-segment system resulted in a substantial decrease of the load necessary for the induction of intended shifts.

The retention of an appropriate structure of the construction of individual morphological elements of the spine is a necessary condition for its resistance to working loads that fluctuate depending on body position as well as on potential carrying an extra load. NACHEMSON [14], on the basis of in vivo research conducted on volunteers with the application of compression-sensitive needle placed in the intervertebral disc L3–L4, found that compression loads increase from ca. 500 N while standing in straight position to 1900 N while bending down on carrying a load of 10 kg. The results published in 1981 were based on pressure measurements carried out inside the intervertebral disc that were transformed into compression load using the results obtained in the experiments conducted on cadavers.

Also in our in vitro research, the range of loads necessary to induce 4-mm compression of both unin-

jured two-segment system and three-segment system amounted on average to ca. 1000 N. As Nachemson's study demonstrates, this is the range of loads occurring also in nature while various life functions are performed.

The range of potential loads and compression strengths affecting the spine may induce resistance-related injuries. This was confirmed in the research of VERNON-ROBERTS [15] who claimed that because microfractures and healing osseous trabeculae are found in the majority of vertebral bodies in post-mortem examinations, particularly in vertically oriented trabeculae beyond the terminal lamina, they occur quite frequently and commonly in our life.

However, strong and abrupt action of compression loads in the spinal axis can result in a sudden fracture of the vertebral body when the body breaks, and bone fragments can be pushed into the vertebral canal [16]. Yet, when compression is combined with bending down, it can be responsible for anterior wedge fracture that concerns only trabeculae in the front part of the vertebral body [17].

5. Conclusions

1. The basic two-segment spine motor system is its most stable functional unit. This is evidenced by applying much higher strength necessary to produce the types of motion under research in the uninjured spine as well as in the injured spine in comparison with the three-segment system.

2. Spinal injury lowers its resistance to loads affecting it. Lower strength induces shifts of similar volume as those in the uninjured spine.

3. In the case of bending in the frontal plane, the load symmetry relevant to this plane is distorted in the examination of three segments. This may be probably related to the asymmetry of ligamentotaxis.

4. Spinal injury in the three-segment system results in load symmetry for the median plane, which can be treated as unintentional.

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