ANIMAL MODELS
IN BIOMECHANICAL SPINE INVESTIGATIONS

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Abstract

The in vitro use of cervical and lumbar spine of quadrupeds in biomechanical researches is presented. The aim of this paper is to show the usefulness of animal’s spine as a model for human spine in biomechanical investigations. In the study, animal vertebral specimens were used, that is cervical sheep and lumbar pig segments chosen because of great model similarity to the human spine. Intact spines and spines after destabilisation by cutting the ligament longitudinal anterior in case of lumbar porcine spine and spines after stabilisation in case of cervical ovine spine were investigated. The extend dislocation was analysed in relation to loads, changes of spinal stiffness and deformations in spinal segments.

Key words: animal models, spine, stiffness.

The animal spines are becoming more and more common models in spinal research. Adult sheep, goat, pig and calf spines have similarities with the human spine. Animal specimens are more easily available and have more uniform geometrical and mechanical properties. There are many problems with the use of human specimens. First - the human specimens have a large variation of geometry and mechanical properties. Second – fresh human cadaveric specimens are difficult to obtain for in vitro experiments (especially from the younger population). Therefore, the animal spines are used for biomechanical analysis (10). A wide variety of implants and procedures are available to a surgeon for the treatment of spinal deformities or to stabilize the spine after fracture. Therefore, many biomechanical investigations have been performed to analyse the influence on changes in spine, and to optimise the fixator systems (3, 5, 12). All of these analyses are performed on the cadaver spines, human or animal.

The sheep cervical spine is stated to be a good model for the human cervical spine, mainly because of a comparable cervical lordosis. Based on the biomechanical similarities of sheep and human spines, demonstrated in studies (2, 7, 8, 13), it appears that the cervical sheep spines are useful as models for disc surgery or bone healing process and can serve as an alternative for the analysis of spinal implants.

On the other hand, the pig and human lumbar spines have similar shape and properties (4). Biomechanical experiments on the spine, especially on the low back (lumbar region) are important for understanding and developing the surgical devices for treating low back pain (11).

In the study, the ovine and porcine spines were used because of many similarities between these spines and the human one.

Material and Methods

The sheep and pig cadaver spines were used for this biomechanical testing. Seven fresh-frozen sheep cadaver cervical spines (C2-C7) from 4-year-old sheep and three pig cadaver lumbar spines (Th14-L6) were used for analysis. The fresh spines were stripped of soft tissues, sparing the ligaments and articular structures. The whole cervical spines were then stored at -20°C until the day of testing when they were thawed. The specimens were kept moistened copiously with saline during the mechanical testing. All biomechanical testing was completed within 5h of thawing (8).

Radiographic and computer tomography examination of the specimens showed no degenerative changes and no deformity or anatomic defects.

The free ends of the vertebral bodies (C2 and C7 in cervical part, Th14 and L6 in lumbar part) were mounted in polyester resin cats and in cylindrical pots in a neutral upright orientation.

All biomechanical testing was performed on a uniaxial material testing machine (MTS 858 Mini Bionix Test System), in a non destructive manner. The loading types performed included axial compression (Fig. 1a) and flexion/extension (Fig. 1b). For flexion and
extension tests, a modified loading system was used, in which the specimen was placed horizontally and an unconstrained motion of the upper and vertebral was permitted in a horizontal plane – Fig. 1b (7, 11). The range of applied loads was presented in Table 1.

The biomechanical testing sequence of the spinal constructs was as follows:

1. Each specimen was first tested intact.

2. a) Lumbar spine was tested after destabilisation by cutting ligament longitudinal anterior and anterior part of disc in L3-L4 segment - Fig. 2a.

   b) Cervical spine was tested after destabilisation and, at the same time, the reconstruction by using anterior plate with interbody graft (Cloward method) in C4-C5 segment - Fig. 2b.

![Fig. 1. Loading system for: a) compression load, b) flexion/extension load.](image)

![Table 1](image)

### Table 1

<table>
<thead>
<tr>
<th></th>
<th>Axial compression</th>
<th>Flexion</th>
<th>Extension</th>
</tr>
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<tbody>
<tr>
<td>Cervical spine</td>
<td>450N/600N</td>
<td>2.9Nm/6.7Nm</td>
<td>0.1Nm/0.2Nm</td>
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<tr>
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<td>(intact/stabilised)</td>
<td>(intact/stabilised)</td>
</tr>
<tr>
<td>Lumbar spine</td>
<td>820N/460N</td>
<td>2Nm/1.3Nm</td>
<td>1.6Nm/0.9Nm</td>
</tr>
<tr>
<td>(pig, intact/destabilised)</td>
<td></td>
<td>(intact/destabilised)</td>
<td>(intact/destabilised)</td>
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![Fig. 2](image)

**Fig. 2** a) the pig specimens after destabilisation, b) the sheep specimens reconstructed using bone graft and anterior cervical plate.

**Results**

Two types of static loads: axial compression and flexion/extension were applied first to the model representing an intact vertebral spine and then to models with destabilisation (lumbar spine) or with application of a fixator (cervical spine).

Figs from 3 to 9 display the results of experimental analysis performed (9, 11).

During biomechanical test with compression, the changes of the force caused by the change of dislocation were analysed. However, in the case of flexion the change of the moment of angular dislocation function was examined.

The research shows the influence of stabilisation on movement range of the spine.

For lumbar spine in axial compression the largest force was observed before destabilisation – Fig. 3a. The same displacement was forced for destabilised and intact specimens but the destabilised lumbar spine required half (50%) of the load to obtain the same displacement. For the maximum value of displacement (6mm) in intact spine, the force was 917 N (±89), and in the spine after destabilisation the force for the same displacement decrease to 460 N (±59).
During flexion to the maximum value of angle (12 deg) the maximum value of moment was 2 Nm (±1.1) for the intact spine and 1.3 N m (±0.8) for the destabilised one. During extension to the maximum value of angle (11 deg) the maximum value of moment was 1.6 Nm (±0.9) for the intact spine and 0.9 Nm (±0.3) for the spine after destabilisation – Fig. 4a.

For the cervical spine in axial compression the largest force was observed after using bone graft and plate technique – Fig. 3b. For the maximum value of displacement (8 mm) in the intact spine, the force was 450 N (±64), however, for the same displacement in the spine with fixator the force increased to 600 N (±86). 

During flexion to the maximum value of angle (12 deg) the maximum value of moment was 2.9 Nm (±1.3) for the intact spine and 6.7 Nm (±2.1) for the spine after stabilisation. During extension to the maximum value of angle (7 deg) the maximum value of moment was 0.1Nm (±0.06) for the intact spine and 0.2 Nm (±0.06) for the spine after stabilisation – Fig. 4b.

The changes of loads for lumbar and cervical spines are non-linear - Fig. 3 and Fig. 4. On the basis of these results the stiffness was determined. As these dependences are not linear, they were determined in ranges. In the graph an intact case and that after destabilisation or after stabilisation were compared. Stiffness was indicated by relationship between load and displacement – Fig. 5.

In Figs 6 to 8 there are presented stiffness characteristics for different loading systems and condition of spines.

Stiffness testing results are presented for compression in Fig. 6 and for flexion/extension in Fig. 7 (lumbar spine) and Fig. 8 (cervical spine).

Compressive stiffness testing results are presented in Fig. 6a for the lumbar spine. There are significant differences of stiffness between the intact spine and after destabilisation. These differences amount even to over 50% value of stiffness of the intact spine to the destabilised one.

![Graph of estimation of rigidity coefficient.](image-url)
Flexural stiffness of lumbar spine is characterised also by large differences before and after destabilisation – Fig. 7. The values of extension stiffness are significantly larger in ranges 0-4 and 4-8, and amount to 60%. The extension stiffness of the spine after destabilisation decreased in relation to the intact spine, in range from 8 to 10 (15%). However, for flexion stiffness along with increase of angle range of flexion the stiffness differences between intact spine and destabilised spine are increased.

Stiffness testing results for compression of the cervical spine are presented in Fig. 6b. There is no significant difference in stiffness (either at start or end of cycling) between both intact and stabilised spines. The most differences of displacement were in range from 4 to 8 mm.

The differences of stiffness relations between the intact cervical spine and that after stabilisation change along with the increase of force exerting an effect on the studied part – Fig. 8. At the same time, it is the part after inserting bone graft and fixator plate that is characterised by greater stiffness in the case of compressing, as well as flexion. However, the differences of stiffness are not equal. That is, by compression there is a visible tendency to decrease the differences of stiffness (distinct in successive interstices of dislocation) before and after stabilisation along with the increase of loading force.

However, in the case of flexion, the stiffness differences are quite significant and they increase along with the rise of loading force even above 50%. It shows that stiffening (fusion) of one functional spine unit is very important for human spine functional physiology.

Additionally, during biomechanical test of lumbar spines, anterior segmental displacements were measured by a displacement gauge attached to either mid anterior aspects of adjacent vertebral bodies (L3-L4 segments) along the ligament longitudinal anterior. In this way, the particular intervertebral displacements were measured.

**Discussion**

Fresh human cadaveric specimens are difficult to obtain for *in vitro* experiments, therefore the sheep and pig spines were used for analysis.

The performed biomechanical investigations showed usefulness of an animal’s spine as models for human spine. The research shows the influence of stabilisation and destabilisation on movement range and stiffness of the spine. The observed difference in cervical spine is important from the point of view of overloading of the spine points above and below the fixated segment. The overloading is usually manifested by increasing of movement range of overloaded parts. In extension, specimens with bone graft and plate showed three times larger moment comparing to the intact specimen. The test makes it possible to analyse the movability and flexibility of a physiological spine and a destabilised one.

![Graph](image)

*Fig. 6.* Compressive stiffness: a) lumbar spine (pig models) in the intact spine and after destabilisation, b) cervical spine (sheep models) in the intact spine and after stabilisation.
Fig. 7. Flexural stiffness of lumbar spine (pig models) in the intact spine and after destabilisation.

Fig. 8. Flexural stiffness of cervical spine (sheep models) in the intact spine and after stabilisation.
Fig. 9. Values of the maximal displacement of segment L3-L4 of intact spine and after destabilisation in different load systems.

A greater stiffness was noted in a flexion rather than in an extension test. That is the basic difference between the data obtained in this test and the data in literature (1, 6) obtained in tests that had been carried out on autopsy specimens. Human autopsy specimens are characterized by a greater flexibility to a flexion (9). It is due to the physiological lumbar lordosis. There is an analogy between the tested pig specimen data and the data obtained in tests of a human lumbar spine carried on by many scientists. It considers especially the rotation data of a lumbar spine. We therefore believe that this kind of specimen may be useful for a practical application in laboratory.

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References