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Experimental and numerical investigations of C5-C6 cervical spinal segment before and after discectomy using the Cloward operation technique

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The main objective of this study was to perform experimental and numerical investigation on human C5-C6 cervical spinal segment before and after discectomy using the Cloward operation technique and to evaluate and compare the stiffness of cervical spines before and after the operation. For the purposes of experimental investigations the cervical spines of four cadavers underwent biomechanical testing. Consequently, in order to perform numerical analysis three-dimensional geometrical and mechanical finite element model of the C5-C6 cervical spinal segment has been constructed. The second step of the investigation was to perform an operation on harvested spines, which corresponded to construction of FEM model of vertebrae after discectomy. Experimental and numerical investigations have been accordingly compared.

Keywords: FEM, the Cloward operation technique, experimental investigations

1. Introduction

One of the most common problems we have faced recently in medical practice is the clinical complication of the intervertebral disc degeneration. The degeneration of discs is a complex process that involves variations in the composition and function of the disc. Some of those regressive changes are connected with ageing process making a problem to be nearly universal [1]. This destructive process most frequently is observed as spondylosis, which is an after-effect of disc herniation and bony spurs familiar to osteophytes. Both osteophytes and disk herniations may expanse intervertebral foramina and vertebral canal causing compression acting on nerve roots and spinal cord, respectively. This may result in severe pain, dysfunction and disability including weakness and paresis of upper and lower limbs. Compression acting on spinal roots results in pain radiating across the back of the shoulder, arm and down to forearm and fingers. Spinal cord compression is responsible for progressive weakness

of lower and upper limbs that leads to complete disability when untreated. Surgical treatment is employed in those cases when pain does not respond to conservative management and when neurological deficits are developed. Surgical intervention relieves pain and prevents permanent disability caused by neurological deficits. A number of operative procedures have been utilised to relieve compression of the cervical spinal cord and nerve roots caused by a disc disease. The Cloward system is one of the most common surgical techniques used with reasonable results. This procedure is aimed at two aspects:

- removal of a disc and/or osteophyte to release pressure on nerve roots and/or spinal cord (familiar to as discectomy);
- fusion of the operated site to achieve a solid bony joint of the two adjacent veretbrae which leaves operated motion segment completely rigid in due course.

The presented study consists of two parts:

1. Experimental test using fresh human cadaver specimens.
2. Development of Finite Element Model for numerical analysis of pre- and post-operative stability of cervical spine to validate experimental investigations.

2. Experimental investigation

Mechanical testing was carried out on four cadaveric human cervical spines. The range of age of cadavers varied from 19 to 87 years. Only C5-C6 vertebrae have been taken into consideration. Before testing cervical spinal segments C4-C7 had been harvested, cleaned of all soft tissues while leaving all the ligamentous structures intact. Four screws (two in the superior and two in the inferior ends of the C4 and C7, respectively) of the proper length and diameter have been implanted in the vertebral bodies in order to leave only C5-Intervertebral Disc-C6 unstable as only this spinal segment was the subject of the investigations. Harvested spines were stored at –20 °C.

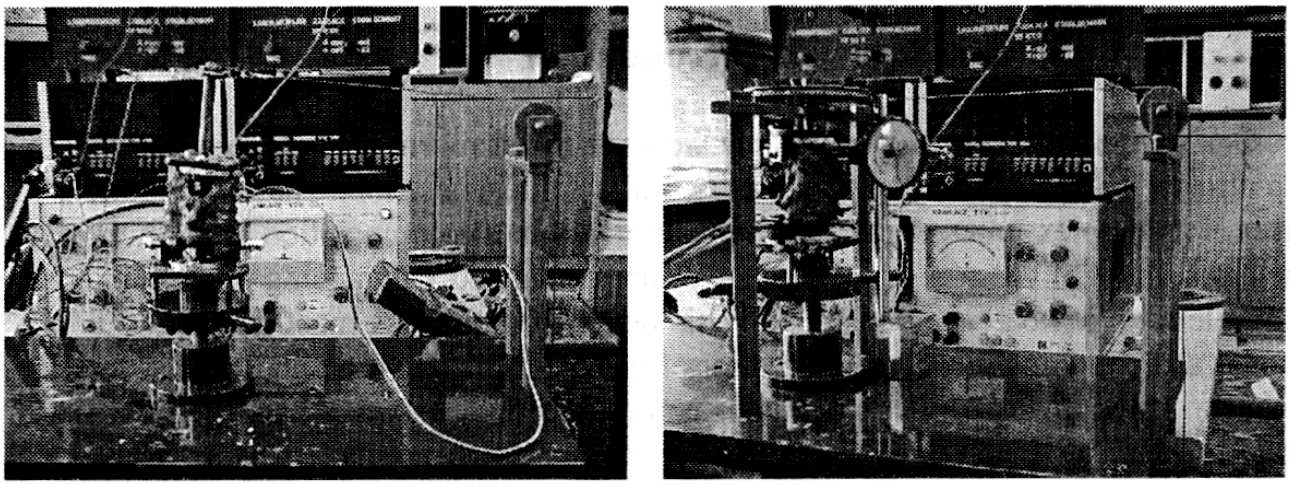

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Fig. 1. Experimental study on the human C5-C6 vertebrae: a) lateral bending, b) axial torque

In the day of testing the specimen was thawed to room temperature and mounted. The inferior vertebrae (C7) have been fixed in all directions using special bolting system, while the most superior vertebral bodies (C4) have been attached to the top plate where different loads were being applied. The extensometer has been attached to two vertebrae (to the anterior part of C5-C6, respectively). Three types of experimental studies have been accomplished – flexion–extension analysis, lateral bending, and axial torque. Loads in flexion–extension states were applied like shown in Fig. 1, while pure torsion moments were used to investigate behaviour of specimen in axial rotation. In flexion–extension and lateral bending tests displacement was measured using extensometers, while in axial rotation, displacement was measured using micrometer. Figure 1 displays two methods of applying loads to the model. All experimental studies had been repeated assuming the cervical spine after performing the Cloward operation technique..

3. Finite element model of the cervical spine before and after discectomy

Mesh geometry was obtained from computer tomographic scans for the shape and diameters of vertebrae of the whole spine. Files containing geometry of the cervical spine have been translated to the form readable for ANSYS 5.4. Surfaces, volumes and element have been generated for the cervical vertebrae [3, 4]. In order to limit the time of the numerical analysis, the number of elements has been significantly decreased (Fig. 2).

In order to analyse the Cloward technique, a special model involving the procedure during the medical operation had been constructed (Fig. 2). From medical point of view the Cloward technique involves hole drilling through a disc and adjacent vertebral bodies until posterior cortex is observed using a specially designed 12-mm drill bit. A disc and osteophyte are removed through a hole using curettes and other instruments. After completion of discectomy a dowel-shaped bone graft 1.5 mm wider than the hole is firmly tapped into place. The graft has a cortical layer at each end and cancellous bone in between.

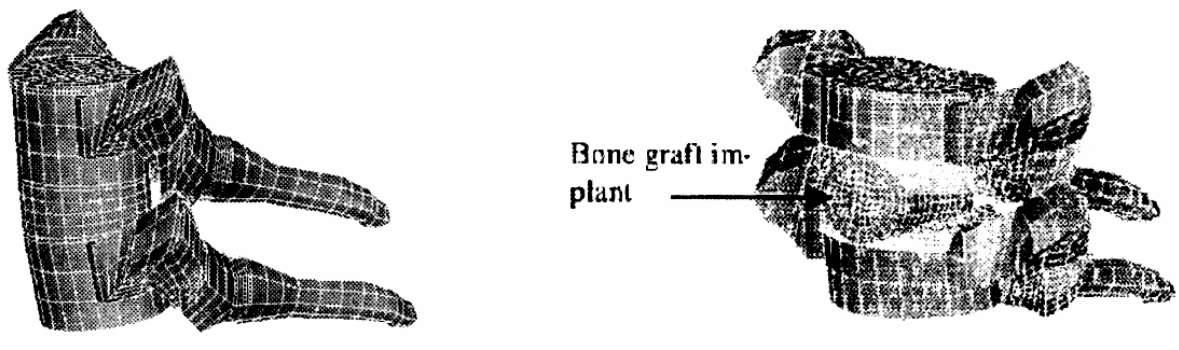

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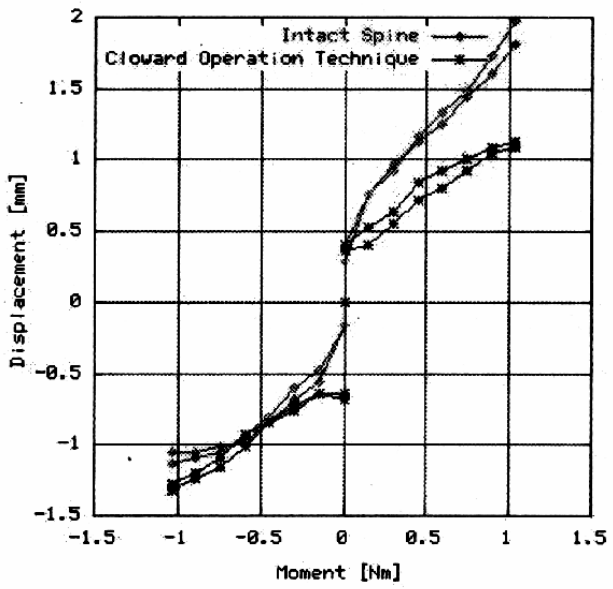
Fig. 2. Finite element mesh for the models: a) intact C5-C6 vertebrae, b) C5-C6 vertebrae after application of the Cloward surgical operation technique

4. Results

Figure 3 displays the behaviour of one of the harvested human cervical spines. 55-year old, male C5-C6 vertebral segment has been tested under different loading conditions. Flexion–extension, lateral bending and axial torsion tests have been performed, respectively.



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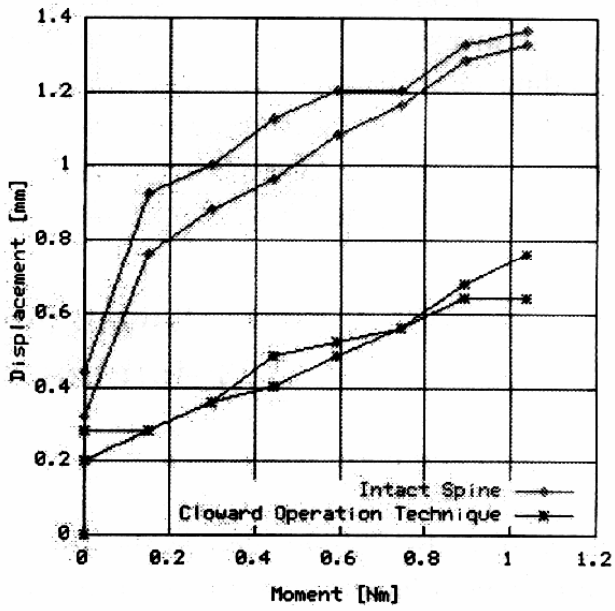

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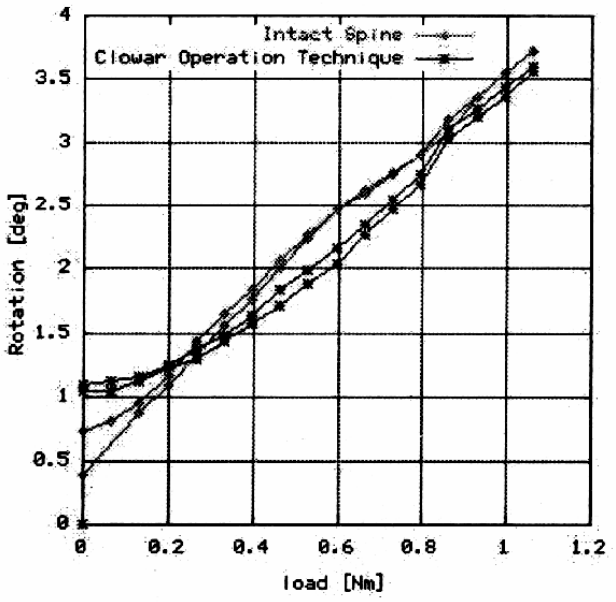

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Fig. 3. Experimental study on the human C5-C6 spinal segment: a) flexion–extension, b) lateral bending, c) axial rotation

In numerical analysis flexural bending moment has been applied first to a model representing an intact C5-C6 vertebral segment and then to the models involving application of the Cloward surgical operation technique. In the case of flexural bending

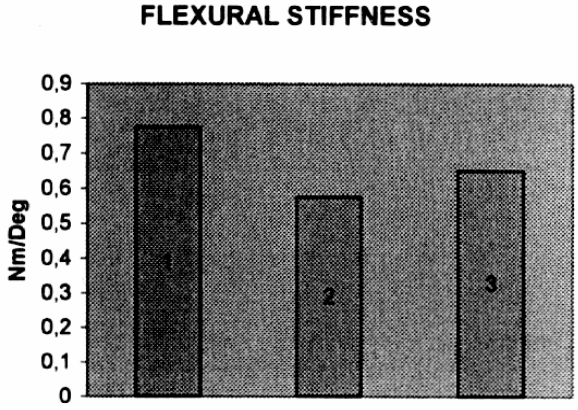

Fig. 4. Numerical analysis vs. experimental investigations – flexural bending: 1 – intact spine, 2 – the Cloward operation technique, 3 – intact spine – experiment, Coe et al. [2]

a pure moment of 2 Nm has been applied directly to the top rigid plate attached to the superior surface of C5 vertebra. Numbers from 1 and 2 in Fig. 4 display the results of numerical analysis performed by authors. For flexural bending results are shown in a form of flexural stiffness calculated as a quotient of a moment (in Nm) to an axial rotation (in degrees). Corresponding results are compared with experimental results obtained by Coe et al. [2].

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