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Preliminary measurements of lumbar spine kinematics and stiffness

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Abstract: The purpose of the presented study was the experimental measurement of lumbar spine stiffness and its range of motion. The dependence of torsion moment of lumbar spine segment on deflection of flexion, extension and torsion was observed during experiments. Stiffness of spine segment was determined from measured data. Human lumbar spine was used for verification of the experimental technique. The sample consisted of one lumbar vertebrae composed by five vertebral bodies and four intervertebral discs. All muscles were removed, however all ligaments were preserved. Experiments were carried out on the test system MTS 858.2 MiniBionix, where loading by axial force and torsion moment is possible at the same time. Special Modular Bionix Spine Test Fixator, attached to the test system was used for the measurements. Loading was controlled kinematically (gradual turning) by keeping the axial force equal zero. Measurement was time-dependent. The results of these experiments are going to be used as input data for creating a model of artificial lumbar spine and new type of artificial disc replacement.

Keywords: spine, lumbar, artificial, kinematics, stiffness

1 Introduction

The lumbar instability is a common disease in clinical practice. Degenerative changes in the discs are always accompanied by osteophyte formation on the margins of the vertebral bodies and remodelling changes in the apophyseal joints. There is a direct relationship between the degree of disc degeneration, marginal osteophyte formation on vertebral bodies and apophyseal joint changes, what means that disc degeneration is the primary event leading to the clinical condition ‘degenerative spondylosis’. There are two surgical methods in treating the disc degeneration (when replacing intervertebral disc): spinal fusion and artificial discs. Disadvantage of fusion is the decrease of mobility in dependence on increase of adjacent vertebrae stability and disc load. None of the currently available artificial intervertebral discs respects all properties of natural disc (no shock absorption, no bending and torsion stiffness). Therefore surgeons demand development of a new artificial disc, which will respects all physiological properties of intervertebral disc. The aim of this project is experimental measurement of lumbar spine kinematics and stiffness. The main problem of this experimental study is the availability of cadaveric human spine specimens concerning ethics, legislation and other problems. Therefore it is a necessary to develop an artificial model which respects all physiological properties of the human lumbar spine, which will be tested instead of real human spine. Therefore, both of these measurements must be in progress simultaneously to determine appropriate function of artificial model. These experimental results will be used as input data for creating a new type of artificial disc replacement which is going to be developed.

2 Testing Procedure

2.1 Principle of measurement

Experiments were carried out on a special spine fixator with six degrees of freedom attached to the test system MTS 858.2 MiniBionix (fig. 1). Loading by axial force and moment was possible at the same time. Modular Bionix Spine Test Fixture allows performing a wide variety of spinal column kinematics studies. Bending moment, axial loads, or a combination of torsion or flexural motions can be measured. The fixture includes multi-channel and axial/torsion systems for analyzing both skeletal and soft tissues during surgical treatment. Servohydraulic Bionix Spine Test Fixture operates with low friction and high stiffness, resulting in high-response and high-performance tests that closely simulate the human spine behaviour. Kinematics measurements such as extension/flexion, medial/lateral and internal/external rotation can be carried out by the Spine Simulator.

The motion segment was loaded by ‘pure’ bending moment in flexion and in extension and by a moment about the z-axis (in torsion). Loading was controlled kinematically (gradual turning) by keeping the axial force equal zero. Range of motion was controlled by the spine fixator in interval (+ 5.3 : -6.3 deg) by flexion/extension. Specimen was loaded just in one direction up to the maximal angle of +1.3 deg in torsion [9]. The response of the specimen [Nm] was measured and stiffness was determined.

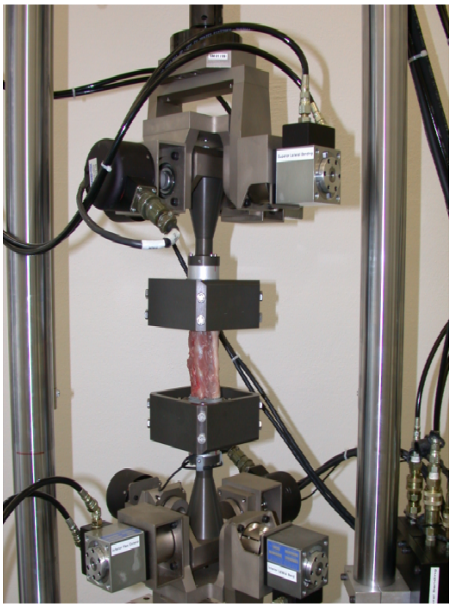

Figure 1 - MTS-Spine fixator.

Application of load was static without inertial forces. In this case just one unembalmed human cadaveric lumbar spine (five vertebral bodies L1-L5) was used. The specimen remained frozen to -20°C until was measured. Tensile forces from muscles were simulated by applying a bending moment [11]. Mobility and stiffness were measured in dependence on time.

Resulting stiffness k was determined by (1), where M_c is a general moment and j is therotation angle.

$$k = \frac{M_c}{j} \quad \left[\mathrm{N.m.deg}^{-1}\right] \tag{1}$$

2.2 Development of new type of artificial disc replacement and model of artificial lumbar spine

Development of new type artificial disc replacement depends on an input data which haven’t been measured completely yet. The artificial model of the lumbar spine has to be assembled according to real physiological properties of the human lumbar spine. This model has to be in accordance with geometry, mechanical properties of bones, ligaments and intervertebral discs. Materials of constituent elements were chosen independently on its biocompatibility. Mechanical properties of bone are discussed in [1]. There is a considerable difference of values of biomechanical parameters and material properties of lumbar spine ligaments depending on source [2 – 8]. Geometry of bone parts was generated directly from CT data and on its basis the model was made. Figure 2 shows the construction of a various types of the lumbar spine ligaments.

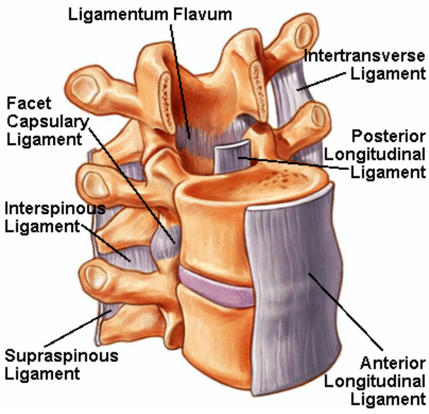

Figure 2 - Anatomy of the lumbar spine [12].

Advantage of this model is the independence of experimental measurements on the human spine specimen source. Combination of a various materials with same mechanical properties of a human spine and taking into account the comparison of surgical techniques influence on the lumbar spine stiffness represent qualities of the model.

3 Results

The three physiological posture of the lumbar spine (flexion, extension, rotation) were measured on a part of one cadaveric lumbar spine (L1-L5). Range of motion was controlled by the spine fixator in interval (+ 5.3 : -6.3 deg) by flexion/extension. Specimen was loaded just in one direction up to the maximal angle of +1.3 deg in torsion [9]. The response of the specimen [Nm] was measured and the stiffness was determined. Maximal stiffness in flexion was approximately 3.5 [$N.m.deg^{-1}$], in extension 0.5 [$N.m.deg^{-1}$] and in torsion 1.6 [$N.m.deg^{-1}$]. These values are in very good accordance other measurements [9]. Increasing rotation angle means increase of ligament loading moment, on the other hand the stiffness decreases (figures 3 and 4). The reason for this behaviour is given by the properties of cadaveric ligament, whose stiffness is decreasing by gradual rotation and itself becomes more elastic [5].

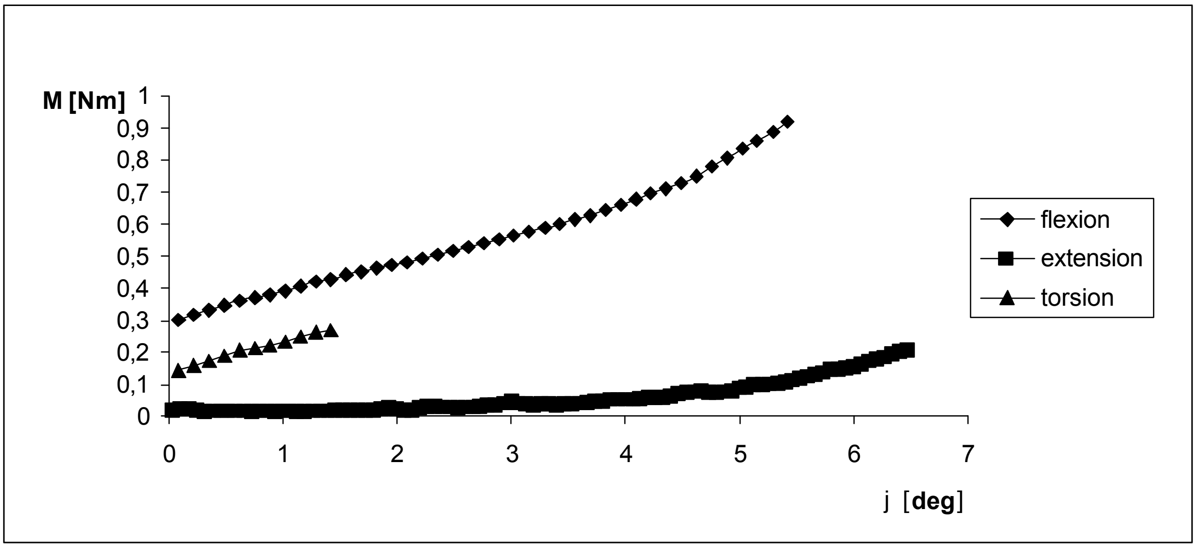

Figure 3 - Graph of motion in flexion, extension and torsion.

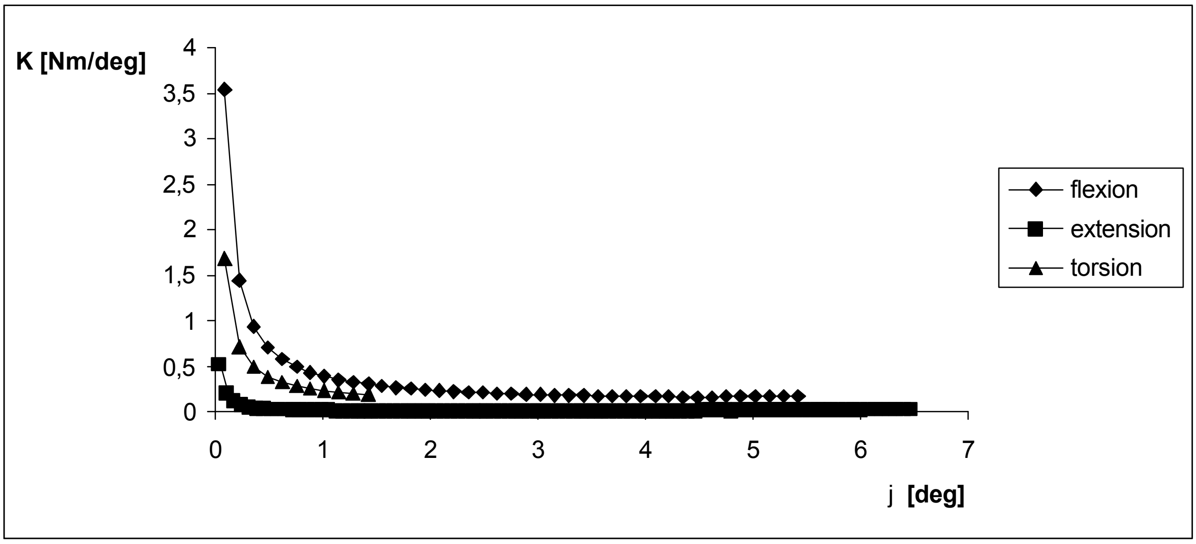

Figure 4 - Graph of stiffness in flexion, extension and torsion.

4 Conclusions

Mechanical testing of cadaveric spine is the best method of investigating mechanical function and failure of the spine. Real artificial models are more suitable for investigation of kinematic processes, such as segment response to its loading. FEM models can be used to explain experimental results, but their predictive power is limited by inadequate knowledge of the material and movement properties of spine tissues. Two main parts of soft tissue affect mobility of the whole spine (intervertebral discs, ligaments). The mechanical properties of cadaveric spines reflect the in-vivo properties. The Specimens should be kept moist during testing. Testing by 21°C is usually acceptable. Number of specimens shouldn't be less than six [10] to obtain adequate results. The shortcoming of our measurement was limited number of specimens. The availability of the human spine represents a big problem for this experimental study. Therefore for further experiments a new artificial spine will be developed. It is being developed in cooperation together with doctors from Motol University Hospital in Prague and University Hospital Aachen- Medical Faculty RWTH and experts from the Institute for a materials science RWTH Aachen. The preliminary results are in very good accordance with literature and therefore the proposed method can be used for human lumbar spine stiffness determination.

Acknowledgements

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