ACTA UNIVERSITATIS CAROLINAE,
KINANTHROPOLOGICA Vol. 47, 2 – 2011 Pag. 166–171

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EXPERIMENTAL DETERMINATION OF SPINAL SEGMENT KINEMATICS

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SUMMARY

This article deals with an experimental work on spinal segment kinematics. A structure of a unique mechanism for spinal segment loading is described. This mechanism can perform periodic loading by pure bending (flexion/extension) or by coupled bending, shear and compression. The kinematics of particular vertebra is measured by means of motion capture technique. In this case, a commercial system Qualisys was used. The raw results are time sequences of marker's coordinates corresponding to moving bodies (vertebra). These data are post processed in a Matlab software and converted to more readable kinematic description using instantaneous axis (or center in 2D) of rotation. These experimental data will be used for numerical determination of load transition ratios between two adjacent vertebras.

Key words: spine, kinematics, experiment, optical measurement, helical axis

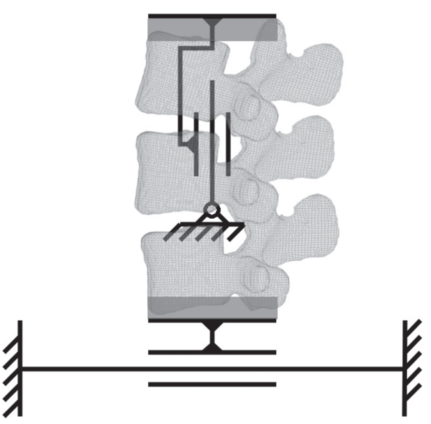

Figure 1. Sketch of loading mechanism

INTRODUCTION

A problem of a low back pain is one of a great problem of present civilization, which in many cases goes together, or is caused by intervertebral disc degeneration. The degeneration of intervertebral discs is getting more frequent problem of ageing population (Adams et al., 2006). One of the methods of a treatment of a low back pain is based on a usage of an artificial disc replacement. There is a problem with a design of mainly used artificial discs (Otáhal et. al, 2008). There are some indications, that the behavior of those implants loadly follows behavior of the real intervertebral disc and the whole intervertebral joint. So, there is need for a new approach to develop an improved disc replacement (Otáhal et al., 2008). Therefore, the better understanding of intervertebral joint behavior in different situations is required, as well as a development of a new methodology for testing of new artificial discs. There is one possible approach for solution of that problem, which is in study of the intervertebral kinematics. It seems that the description of kinematics through the usage of helical axis is recommended (Holub et al., 2008; Wachowski et al., 2009; Schmidtet al., 2008). It seems that the intervertebral kinematics dependents on an actual condition of the whole intervertebral joint. Therefore, there were developed a new in vitro method for experimental analysis of intervertebral kinematics, which is possible to apply to testing of new artificial discs and which is based on description of the kinematics through the use of helical axes. The Qualisys system was used for obtaining raw data of spinal movements. The porcine lumbar spine was used as a model of human spine.

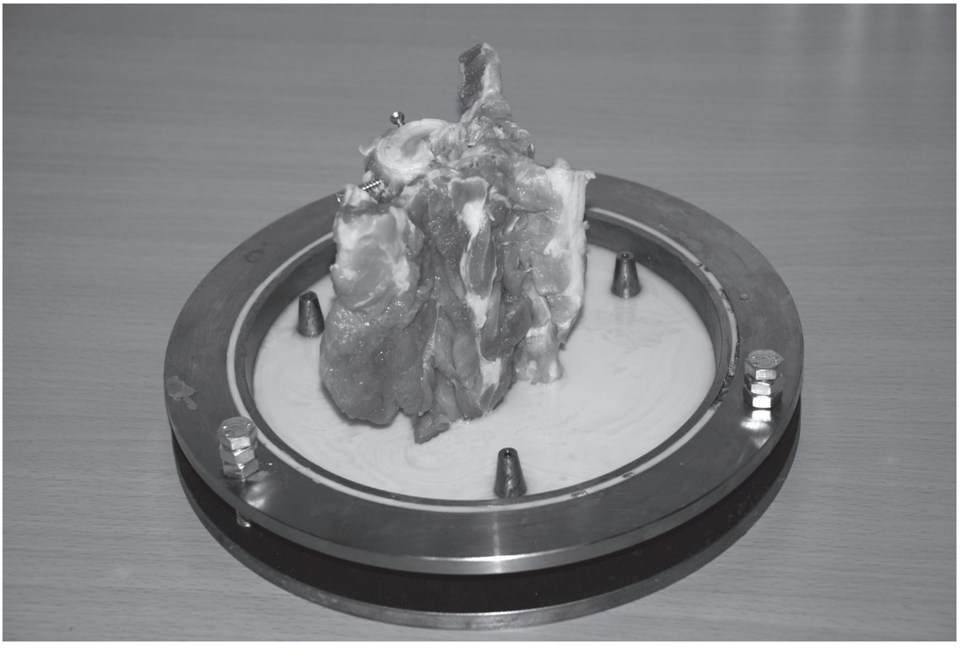

Figure 2. Sample casted in Axson F16
Special device for spine segment loading

In order to obtain relevant data on intervertebral kinematics a unique testing mechanism was designed and machined. The schematic representation of the mechanism is shown in Figure 1. A spine is loaded by rotating the upper part of the mechanism around fixed axis.

Thereby it is possible to investigate the flexion/extension and lateral flexion/extension movement. A momentum of load is generated by servomotor and subsequently transmitted with ratio 1/4 or 1/8 to spine with respect to angular step size and momentum magnitude. A servomotor is controlled via a microchip module SOS-AT connected to PC. An angle increment and amplitude as well as loading rate can be easily controlled via PC. Additionally, the horizontal and/or vertical sliding connections can be fixed and so the coupling of bending, shear and compression can be achieved. In this case, the coupling ratios are influenced by setting the position of the axis of rotation. This device is capable to perform full loading up to spine segment length of six vertebras.

A motion of particular vertebra was measured by means of a motion capture method. The commercial system Qualisys records a time sequence of binary images of reflex markers. Since, several synchronized cameras were used. 3D positions of markers in

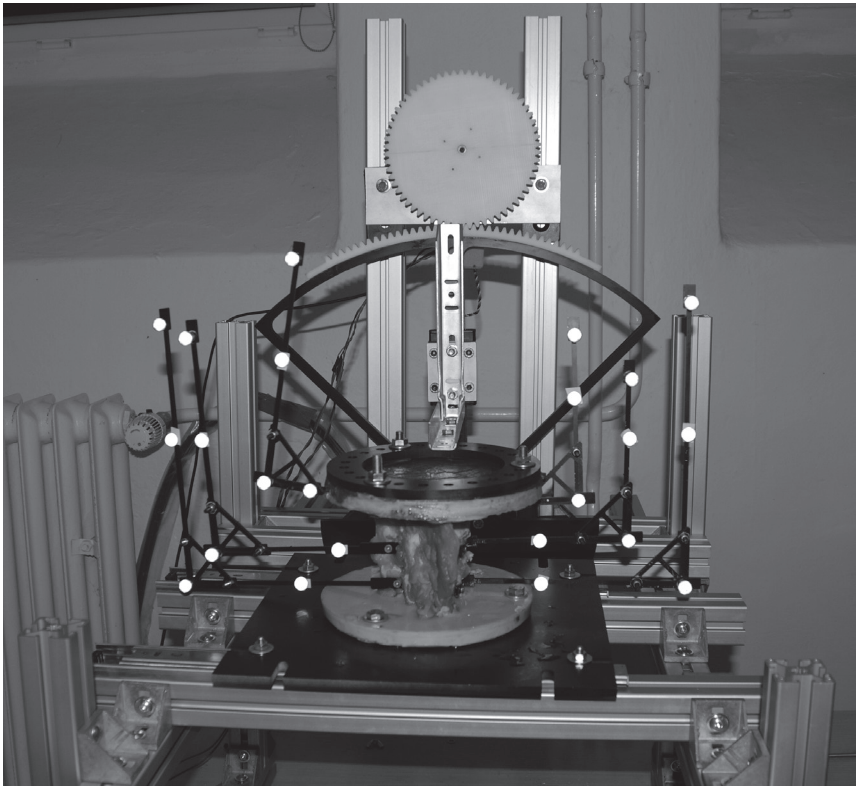

Figure 3. L5–L3 segments of porcine spine fixed into testing device. 8 reflex markers in two consoles was attached on each vertebra, one console with four markers onto procesus spinosus and second on ventral shape of vertebral body.

time could be reconstructed. The experiment was carried out on L3–L5 vertebra spinal segments. At first, the bottom and upper vertebra were fixed in a cylindrical cast as it is shown in Figure 2. The material of casting is Axson F16. This material was chosen with regard to a short hardening time and sufficient stiffness. Than the segment was fixed in a neutral position and connected to the loading mechanism. Qualisys system was calibrated afterwards. The positions of three significant points (on processes) on each vertebra were measured by a palpation pen for vertebra coordinate system determination. The special consoles with markers were attached to each vertebra as it is shown in the Figure 3. The consoles are used in order to achieve higher amplitudes of markers motions thus reduce a relative error of positions determination. Each vertebra carried eight markers although trio of markers is sufficient for description of the position in 3D space. Nevertheless, this over determination highly reduced position error. Than the periodic quasistatic loading with amplitude 10° was applied and the motion was recorded with 50 fps.

Data postprocessing

The experiment output contained a file of markers coordinates. Savitski-Golay smoothing filter was used during data evaluation of lumbar spine segment kinematic. Any general movement of a body in space can be described by helical axis. Any motion can be broken into a rotation around and the translation along this instantaneous axis of rotation. The only exception is when the body is just translating in some direction. A plane loading was applied to lumbar spine segment by our loading device. The simulated movement was in direction of frontal-dorsal flexion. Because of this plane movement, the helical axis became instantaneous centers of rotation.

Commercial software MATLAB was used for evaluating the centers of rotation. Our script computes with the instantaneous locations of each marker on each vertebra, and with the mean position of markers from each vertebra. Before starting the procedure the positions of markers of each vertebra were transformed into local coordinate system of the lower vertebra which means positions of L3 markers were transformed into L4 coordinate system, and L4 into L5 coordinate system. The outputs from this procedure were vectors, which described the positions of centers of rotation in local coordinate for each vertebra movement. The global coordinate system was defined on the loading device.

The movement of rotation centers can be seen in the Figure 4. It is obvious, that it will be important to separate a movement in direction of flexion from a movement in direction of extension.

RESULTS

Presented results of positions of helical axes of healthy porcine, L5–L3 intervertebral junction, were obtained by this method. L3 vertebra was loaded in range from 10° of flexion to 10° of extension. The points of intersections of helical axes with XY-plane are shown in the Figure 4.

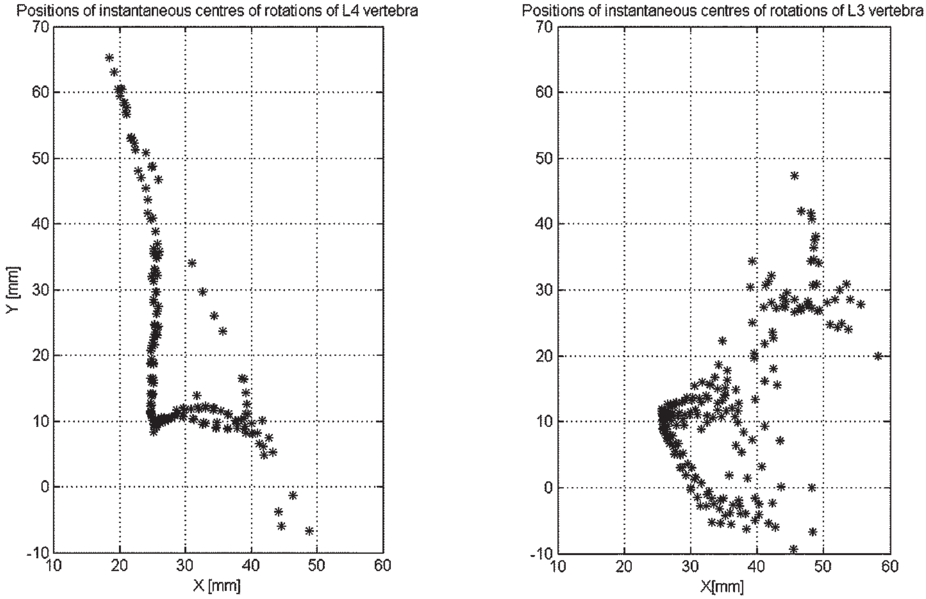

Figure. 4. Points of intersection of helical axes with XY-plane. L4 vertebra data are shown in the left and L3 in graph in the right side. Ranges of centres of rotations are similar, but the trends of data curves are different, which is caused by different stress distribution of L3–L4 and L4–L5 intervertebral joint.

DISCUSSION

Presented method seems to be useful for the intervertebral kinematics description. However, this method has problem in a description of kinematics close to bounds of range of movement. In other words it the upper and the lower dead point (10° extension, 10° flexion). Intervertebral kinematics is one of parameters which is being markedly changed at the most of spinal diseases. The description of intervertebral kinematics using helical axis can help us for observation the consequences of the spinal diseases affecting a spinal behavior as well as the treatment methods. Combination of presented method with using of porcine spine as a model of human spine seems to be for fundamental testing of artificial discs.

ACKNOWLEDGEMENTS

This article was supported by grant of Czech Technological Agency (TAČR) no. TA01010860, and by student grant of Czech Technical University (SGS) no. SGS10/155/OHK2/2T/12 , and by the grant SVV-2011-263601.

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EXPERIMENTÁLNÍ URČENÍ KINEMATIKY PÁTEŘNÍCH SEGMENTŮ

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SOUHRN

Tento článek je zaměřen na experimentální kinematiky spinálního segmentu. V této práci je popsán unikátní mechanismus vyvinutý k zatěžování spinálního segment. Pomocí tohoto mechanismu jsme schopni zajistit zatížení testovaného spinálního segment ohybem (ve smyslu flexe extense), nebo kombinací ohybu, smyku či komprese. Kinematika jednotlivých obratlů je pak měřena pomocí metody motion capture. V našem případě pomocí systému Qualisys. Výstupem z tohoto systému pak je pak časové sekvence souřadnic markerů, které odpovídají danému obratli. Tato data jsou poté zpracovávána pomocí softwaru Matlab, a dále převedena na použitelnější kinematický popis pomocí okamžitých os (center ve 2D) rotací. Tato data pak budou použita pro numerické určení přechodových charakteristik mezi dvěma sousedními obratli.

Klíčová slova: páteř, kinematika, experiment, měření optickou metodou, helikální osy

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