Acta of Bioengineering and Biomechanics
Vol. 8, No. 2, 2006

Experimental investigation of the lumbar spine – influence of destabilization on the stiffness characteristic

AGNIESZKA SZUST

Wrocław University of Technology, Faculty of Mechanical Engineering,
Faculty Division of Deformable Body Mechanics

The lumbar spine region is most often affected by disorders. These disorders lead to instability in the motion segments. Many surgical procedures have been undertaken to reduce instability and restore the function of the spine. Spinal fusion is most commonly used to stabilise unstable motion segments. Consequently, immediate stability is provided by instrumentation just after surgery. The segment is being kept aligned until the fusion process is completed.

This study was undertaken to evaluate the influence of posterior instrumentation on the stabilisation of lumbar motion segment. The author measured and compared the stiffness of human lumbar spine destabilized in two ways and stabilised with two posterior stabilisers.

1. Introduction

The injury in a spinal region in most cases requires the stability improvement by technical means (implants). As in any field of surgery, the choice of a proper surgical treatment in spinal surgery is of vital importance because of the role of the spine in the proper functioning of the human organism [1].

The evolution of stabilizing systems has been determined by the changes in the views on corrective procedures and the extent of stabilization for different surgical approaches (the anterior approach through the abdominal cavity and the chest or the classical posterior approach) and by the needs of experienced surgeons who use implants in the surgical treatment of the spine.

The best experimental method available today is *post-mortem* experimental investigation of human preparations being anatomically and physiologically normal. Such investigations should be carried out under biomechanical conditions, being the best possible representation of the natural physiological conditions. For this reason, *post-mortem* preparations with their ligament structure intact and possibly largest spinal segments should be investigated. Due to the complexity of the biomechanical and physiological processes and the anatomic conditions, it is best to carry out such experimental investigations on human *post-mortem* preparations [5], [7].

This paper presents the author's experimental investigations carried out on *post-mortem* preparations of the human lumbar spine. Their aim was to examine the influence of a stabilizing system on the improvement in the functional mobility of a damaged motion segment of the spine. This influence was studied for different kinds of injury to the spinal segment examined.

2. Material and methods of investigation

Eleven *post-mortem* preparations of the human lumbar spine were investigated. All these preparations came from male donors at the age of 18–62 (table). Anatomically and physiologically normal segments, each with four healthy vertebrae and three undamaged intervertebral spaces, i.e., anatomically normal intervertebral discs, were taken for the investigations (figure 1). The test preparations were marked with the symbols shown in the table. The stabilizing systems used were marked with the following by symbols: S1 – stabilizing system no. 1 and S2 – stabilizing system no. 2. The preparations were divided into two experimental groups: one made up of the preparations destabilized by cutting the longitudinal ligament and the other consisting of the preparations destabilized by cutting the supra- and interspinous ligaments (figures 2 and 3). Each time the damage to ligaments was done in one spinal motion segment L2–L3.

Fig. 1. Lumbar spine preparation L1–L4 taken and cleaned

Table. The characteristics of the specimens examined

No.	Preparation (symbol)	Age	Height	Weight
1	L 4	61	174	62
2	L 5	22	172	80
3	L 6	30	194	91
4	L 7	18	174	72
5	L 8	62	159	61
6	L 9	18	164	71
7	L 11	42	166	70
8	L 12	20	164	56
9	L 13	30	168	70
10	L 14	20	175	74
11	L 15	58	163	69

The experiment was carried out under axial compression and functional loading. A physiologically intact preparation, a destabilized preparation and a preparation subjected to the influence of two stabilizing systems (successively implanted in the region of the damaged motion segment) were investigated.

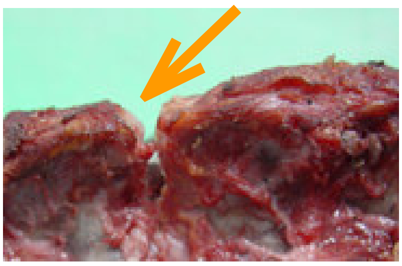

Fig. 2. Preparation destabilized by cutting supra- and interspinous ligaments at segment L2–L3 level

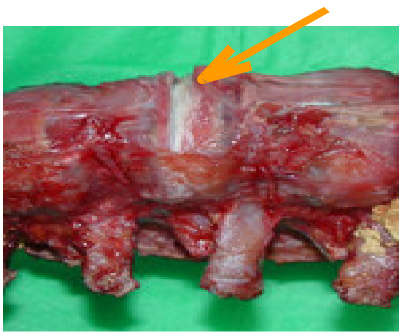

Fig. 3. Preparation destabilized by cutting anterior longitudinal ligament at segment L2–L3 level

3. Results

The test results were analysed taking into account the kind of loading and the destabilization method.

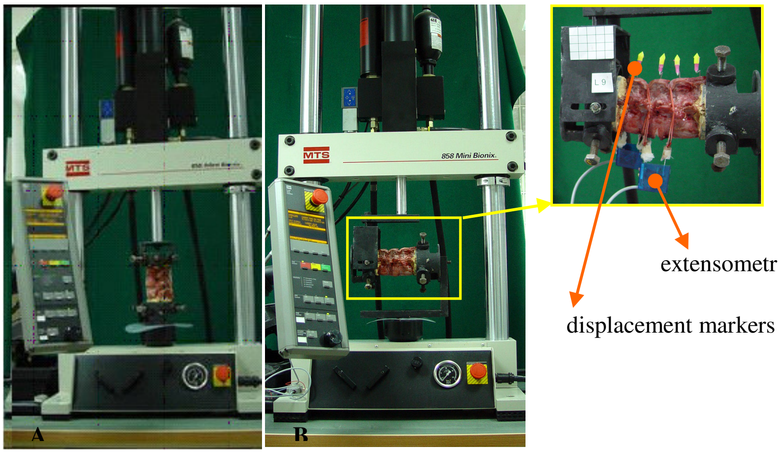

Fig. 4. MTS-Bionix testing machine module with test preparation inside:
A – axial test loading system, B – bend/hyperextension test loading system,
C – preparation after destabilization with mounted extensometers and displacement markers

3.1. Axial compression test results

In the axial compression test, the kind of destabilization did not greatly affect the force value in the test cycles in which the stabilizers S1 and S2 were used. After the stabilizing systems (stabilizer S1 and stabilizer S2) were mounted, we obtained the following test results: the test with stabilizer S1 – 63% of the preparations tested were characterized by a higher stiffness than that of the physiologically normal preparations. Moreover, none of the preparations tested showed stiffness below 80% of that of the physiologically intact preparation, which from the biomechanician's viewpoint can be regarded as an implantation success and the fulfilment of the expectations associated with the stabilizer.

In the test with stabilizer S2, 45% of the preparations tested were characterized by a higher stiffness than that of the physiologically normal preparations. Three preparations stabilized by stabilizer S2 had greater flexibility (below 80%) than that of the physiologically intact preparations.

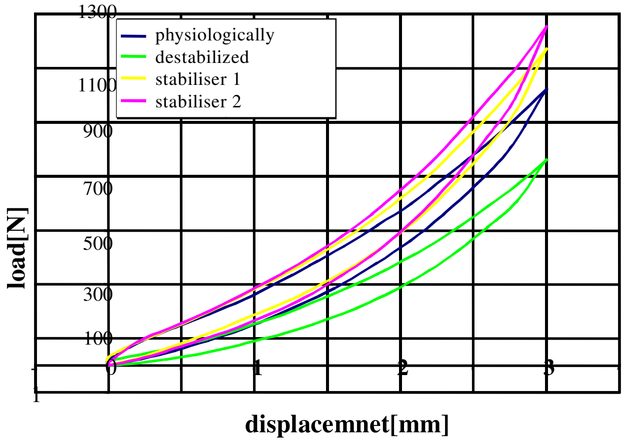

Fig. 5. Comparison of typical deformation curves for one preparation subjected to axial loading

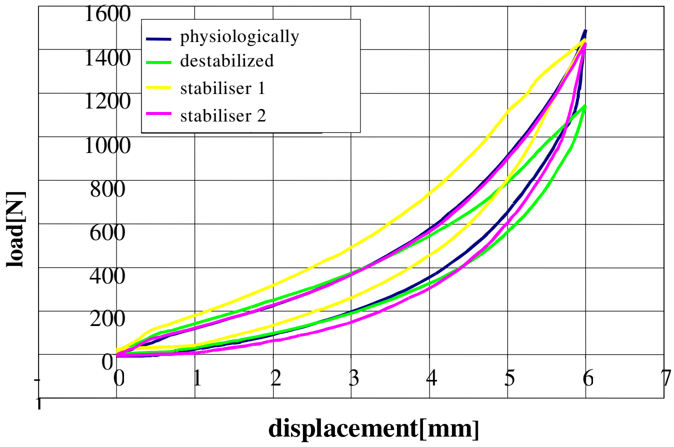

Fig. 6. Comparison of typical deformation curves for preparation L6 for different loading cases

3.2. Test results for bend forcing load

In this experiment, the following results were obtained: all the preparations were characterized by much greater flexibility than that of the intact physiological preparations tested. The flexibility was below 80% of that of the physiologically normal preparation. Hence, it can be concluded that it is absolutely imperative that a system restoring the mechanical stability of the spinal segment tested should be introduced in this case.

In the bending test of the spine system equipped with stabilizer S1, 82% of the preparations were characterized by a greater stiffness than that of the physiologically intact preparations. The other preparations showed a slight reduction in stiffness, i.e., by 3% and 20% below the stiffness of the physiologically normal preparation.

In the bending test with stabilizer S2, a greater stiffness of the system was observed in 73% of the cases of which 45% showed considerable overstiffness in comparison with the physiologically normal preparations. A significant difference in the force values obtained between the group with stabilizer S1 and the one with stabilizer S2 was observed, depending on the kind of stabilization, i.e., stabilization of the anterior or posterior spinal column. For either stabilizer the preparations destabilized by damaging the posterior spinal column became more flexible than the preparations destabilized by damaging the anterior spinal column.

3.3. Test results for hyperextension forcing load

In this test, all the preparations destabilized showed a considerable increase in the flexibility in comparison with the physiological preparation. The flexibility in the hyperextension test was much greater than that in the bending test irrespective of the destabilization method (damage to the anterior or posterior spinal column).

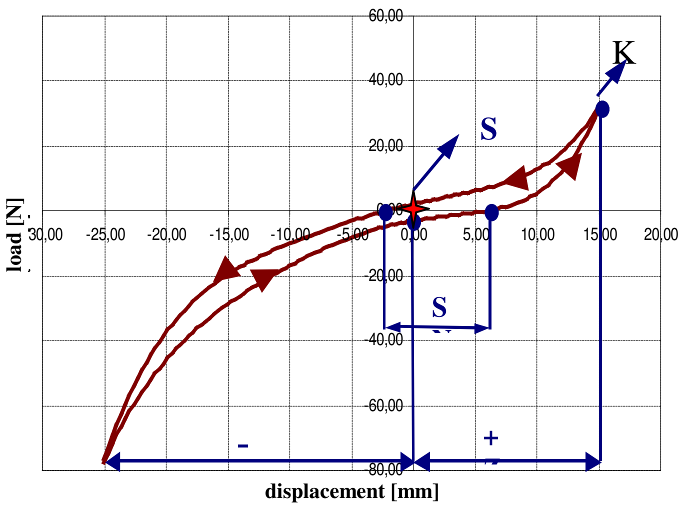

Fig. 7. Force versus global displacement in the system simulating bend–hyperextension displacement, where: SN – neutral zone, –ZR – maximum range of motion in bending, +ZR – maximum range of motion in hyperextension, S – beginning of test cycle series, K – end of each cycle

Similar results were obtained for the preparations stabilized by stabilizer S1 and the ones stabilized by stabilizer S2. In both cases, 54% of the preparations showed smaller stiffness than the one characterizing the physiologically intact preparations, but the smaller stiffness did not significantly weaken the function of the implants. The preparations destabilized by damage to the posterior spinal column showed a greater stiffness than that of the group of preparations destabilized in the anterior spinal column. The above comparison applies to the group of preparations re-stabilized by means of stabilizers S1 and S2.

4. Conclusion

The investigations showed marked changes in the stiffness of lumbar spine as a result of the changes in its stability. In almost each case, excessive hyperextension of the spinal system caused by the introduction of a stabilizer was recorded. An increase in the system stiffness was observed regardless of the stabilizer implanted. The investigations have demonstrated the clinical importance of the results obtained in the treatment of spinal pathologies such as: scoliosis, degenerative changes or post-accident damage. According to hospital statistics, lumbar spine vertebrae from L1 to L3 are most often damaged as a result of accidents. From the clinician's viewpoint, the investigations have demonstrated the great importance of the choice of an implant and a stabilization method appropriate for the patient's age (for the structural condition of the bone tissue) and for the pathological state.

References

[1] BĘDZIŃSKI R., SZUST A., *Badania podatności kręgosłupa lędźwiowego pod wpływem stabilizacji transpedikularnej*, Materiały konferencyjne XLII Sympozjon *Modelowanie w mechanice*, 2003.

[2] CRIPTON P.A., BRUEHLMANN S.B., ORR T.E., OXLAND T.R., NOLTE L.P., *In vitro axial preload application during spine flexibility testing: towards reduced apparatus-related artefacts*, Journal of Biomechanics, 2000, 33, 1559–1568.

[3] MARRAS W.S., GRANATA K.P., *Spine loading during trunk lateral bending motions*, Journal of Biomechanics, 1997, Vol. 30, No. 7, pp. 697–703.

[4] NEUMANN P., OSVALDER A.L., NORDWALL A., LOVSUND P., HANSSON T., *The mechanism of initial flexion-distraction injury in the lumbar spine*, Spine, 1992, Vol. 17, No. 9, pp. 1083–1090.

[5] ROHLMANN A., BERGMANN G., GRAICHEN F., *Loads on internal spinal fixators measured in different body positions*, Eur. Spine Journal, 1999, No. 8, pp. 354–359.

[6] SHONO Y., KANEDA K., ABUMI K., MCAFEE P.C., CUNNINGHAM B.W., *Stability of posterior spinal instrumentation and its effects on adjacent motion segments in the lumbosacral spine*, Spine, 1998, Vol. 23, No. 14, pp. 1550–1558.

[7] WILKE H.J., WENGER K., CLAES L., *Testing criteria for spinal implants: recommendations for the standardization of in vitro stability testing of spinal implants*, Eur. Spine Journal, 1998, Vol. 7, pp. 148–154.