*Acta of Bioengineering and Biomechanics*
*Vol. 3, No. 2, 2001*

# Experimental investigation of cervical spine fixators

CELINA PEZOWICZ

Institute of Machine Design and Operation, Wrocław University of Technology,
Wybrzeże Wyspiańskiego 27, 50-370 Wrocław, Poland

The author uses a holographic interferometry technique to measure the displacement of cervical spine fixators when applied to a section of cadaveric spine which is loaded in bending and torsion. The analysis was undertaken to assess the effect of stabilizers implanted in the cervical section of the spine on the load bearing mode and the rigidity relationships.

*Key words: cervical spine, fixator plates, displacement distribution*

## 1. Introduction

It has become a common practice to apply fixators to all segments of the human spine, particularly to its cervical segment, with the treatment varying, depending on the injury, the resulting instability and its extent. However, once an implant is introduced into the spine, many problems connected with its functioning and use arise. Although there are several techniques of remodelling the damaged parts of cervical spine or recovering its stability, there are no clear guidelines for the use of anterior or posterior fixators. A fixation procedure is chosen mainly on the basis of an assessment of the clinical instability. Therefore *in vitro* studies of cervical implants are essential for determining the effect of these elements on the stability of the cervical spine and on the changes in its rigidity and the way it bears loads. This is why numerous comparative studies of suitable implants are made to determine, for example, to what degree the stability of the spinal column or the ability to withstand physiological or limit loads is recovered by applying the particular implants. Such studies have been conducted by, among others, the authors of [1], [6], [14], [15].

Some researchers focus their attention on fixators implanted from either anterior (plate fixators) [10], [4] or posterior approach (wire fixators and rod fixators) [16] or deal with both methods of fixation [5], [13]. The parameters analyzed are related to the implant's rigidity or to the changes in mobility of the segments above and below the fixation. The techniques of destabilizing the segment tested differ widely: Kotani et al. [7] simulated cervical spine destabilization by injuring (severing) selected ligaments and the intervertebral disk, whereas the Richman et al. [10] used animal (porcine) models in which one motion segment was destabilized by removing the vertebral body and then the system was remodelled by introducing an anterior methacrylic graft.

As already mentioned, researchers concentrate on comparisons of various stabilization techniques in different configurations and in different simulated instability conditions. But many report widely different or even contradictory experimental results for the same problems, e.g. [4], [6].

The differences often stem from variety of the models tested (autopsy preparations, animal specimens) and the way they are prepared (storing and testing conditions and testing time). All these factors affect greatly the results obtained. Hence it is rather difficult to determine which of the tests yield results close to the effects observed in actual conditions.

No experimental studies have been conducted on physical models which would ensure identical test conditions for different loads simulated and kinds of destabilization and for analyses of the phenomena occurring in the systems with inserted implants and thus ensure repeatability of both the tests and the results obtained. If the parameters of the modelled physical system could be controlled, it would become possible to assess accurately the phenomena studied. It is difficult to achieve such control in the case of biological preparations since they preserve certain distinct individual features associated with the individual's age, sex, etc. and with the treatment of the test specimens, which cannot be eliminated. All these factors affect considerably the test procedures and conducting.

The effect of fixators on the pattern of deformation of the cervical structures and on the stresses and strains appearing in the implants under loads has not been assessed yet.

Biomechanics of the cervical spine has been rarely investigated in Poland. The results reported come mainly from clinical studies which do not take into account the mechanics and biophysics of the phenomena studied. Therefore it is necessary to extend the knowledge about the cervical spine by conducting experimental investigations.

## 2. Subject and aim of studies

The subject of the experimental studies was a functional motion segment of the human cervical spine. This segment has been chosen because epidemiological studies indicate that it is the most often injured link in the cervical spine. One of the most frequently reported cases of destabilization is the loss of physiological functions by the intervertebral disk. This can be remedied by removing the damaged disk, replacing it with a transplant and stabilizing it by an implant.

To assess the effect of fixators on the load bearing pattern and the rigidity relationships, a physical model was made. Its characteristic can be described as follows:

- the model included two real cervical vertebrae (C5 and C6) with the soft tissue removed but with the bone structure left intact;
- the articular junctions on the articular processes in the motion segment were remodelled;
- the motion segment was fixed on the lower surface of the vertebral body of lower vertebra C6; vertebra C5 could move within the limits specified in the test plan;
- plate fixators were inserted in turn into the system; the selection of fixators was determined by the wide use of anteriorly implanted fixators (plates) in clinical practice in Poland;
- since mechanical properties of the graft inserted change in the course of stabilization (vertebral arthrodesis–bone union), two kinds of graft and thus two stabilization model versions were simulated:

a) the first version of the model does not include a bone graft routinely inserted into the space left when the intervertebral disk is removed: in the first few days after fixation, the fixator bears the loads and the graft does not participate in it, hence an empty interbody space is left in the physical model to simulate this situation; an actual X-ray image of two cervical vertebrae with the graft inserted and fixation in the form of a plate implant is shown in figure 1a; there is no bone union between the vertebral bodies and the implant in the first few days following fixation;

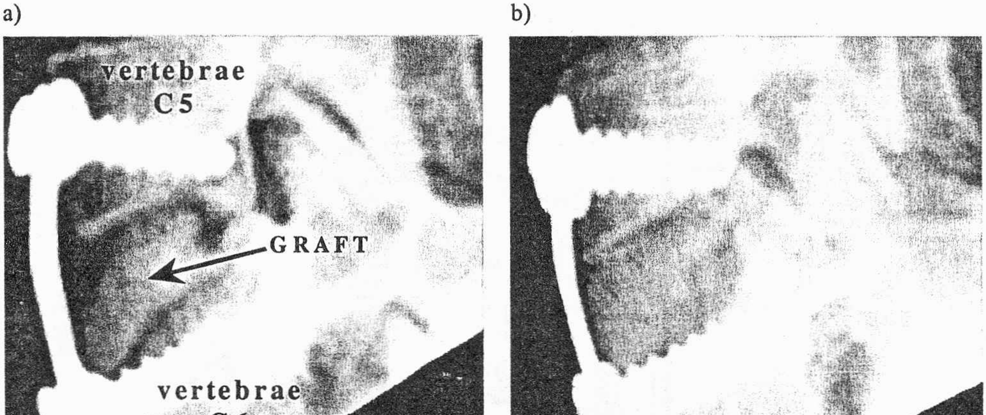


Fig. 1. X-ray pictures of two cervical vertebrae with plate fixator and bone graft inserted between vertebral bodies: a) the first few days after insertion of the graft, b) 3 months after insertion of the graft [8]

b) the second version of the model includes a graft whose mechanical properties are similar to those of normal, physiological bone structure of cervical spine – figure 1b (full bone union between the vertebral bodies and the graft).

This model made it possible to conduct investigations in order to assess the effect of plate fixators anteriorly implanted on the rigidity of the stabilized system and on the load bearing pattern. The models constructed allowed us also to assess the bone graft's contribution to the post-implantation stability of the spine.

Despite the simplifications introduced, it is the first model of this kind which enables an assessment of the changes occurring in the cervical spine during the plate-implant treatment of injuries caused by overloading.

Many different measuring techniques are currently used to analyze stresses and strains in bone structures and implants. The techniques most widely used for the experimental assessment of displacements and deformations are: strain gauge techniques, photoelasticity, photoelastic coatings and, in recent years, laser techniques such as holographic interferometry or speckle photography [2].

Holographic interferometry opens up new possibilities in the stress and strain analysis. This technique makes it possible to conduct no-contact, non-destructive tests on real (original) objects, eliminating the need to use their models. It can be used to investigate objects of any shape and with any surface structure [3].

## 3. Material and method

In order to carry out the studies, a loading system shown in figure 2 was built. The initial loads calculated and force increments which followed from the obtained density of interference lines were applied.

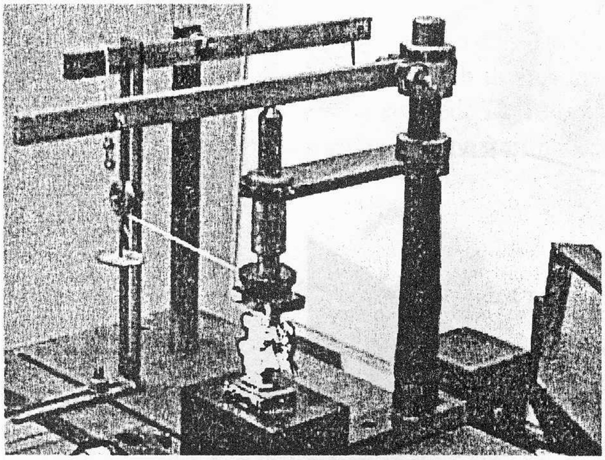


Fig. 2. Loading system

A suitable measuring system allowing the use of the double exposure technique was built. The measuring system was constructed on the basis of literature data and our own experience in holographic interferometry. The optical system applied to the tests is shown in figure 3.

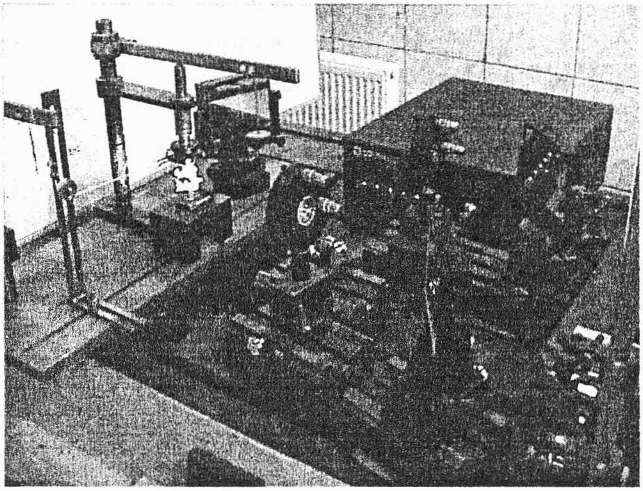
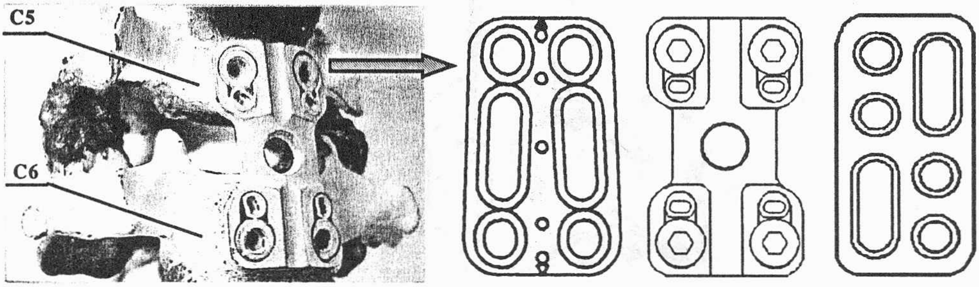


Fig. 3. Optical system

The investigations were conducted on a physical model which incorporated two actual cervical vertebrae C5 and C6 with reproduced junctions on the articular processes. A photo of the physical model of motor segment C5–C6 with the stabilizing plate is shown in figure 4.

For the preliminary assessment of the effect of the plate implants on the rigidity relationships in the stabilized section of the spine chosen mechanical parameters of the implants were estimated (the table).



a) b) c)

Fig. 4. The physical model of motor segment C5–C6 with the stabilizing plate:
a) Caspar (Aesculap), b) Codman (Johnson & Johnson), c) Dero (LfC)

Table. Chosen mechanical parameters (calculated) of the implants

| Type of stabilizing plates | Bending stiffness $EI_z$ [Nm$^2$] | Compression stiffness $EA$ [N] | Rotation stiffness $EI_s$ [Nm$^2$] |
|---|---|---|---|
| Caspar | $28.85 \cdot 10^{-2}$ | $23.92 \cdot 10^{5}$ | 43.02 |
| Dero | $49.02 \cdot 10^{-2}$ | $20.80 \cdot 10^{5}$ | 63.82 |
| Codman | $52.59 \cdot 10^{-2}$ | $28.19 \cdot 10^{5}$ | 43.99 |

In order to determine the effect of plate implants on the rigidity of the stabilized section of the cervical spine and to define the role of the bone graft in the bearing the loads acting on the segment C5–C6 investigated (this segment was chosen because of the high incidence of injuries reported in its case), two schemes of stabilization involving a bone graft were investigated, i.e.

- motion segment C5–C6 without the bone graft zero (in the first few days after fixation the graft does not bears the loads),
- motion segment C5–C6 with mechanical properties of the bone graft similar to those of normal bone tissue.

The forces simulating physiological loads which occur during the performance of normal living functions by man, i.e. axial compression ($F_{ac}$ = 50 N – weight of head), extension ($F_{ex}$ = 1 Nm), and torsion ($F_r$ = 0.15 Nm), were introduced into the above models [11]. The scheme of loads applied to the models investigated is shown in figure 5.

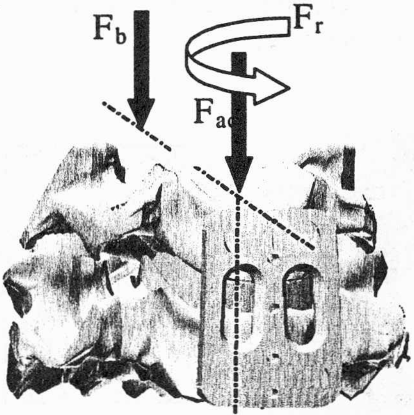


Fig. 5. Scheme of loads applied to the models investigated: axial compression ($F_{ac}$), extension ($F_{ex}$), rotation ($F_r$)

## 4. Analysis results

Holographic interferograms (figure 6) obtained from the investigations were used to determine the displacements of the stabilizing plates under different load conditions.

Then the distribution of displacements in the transverse or longitudinal plane of the stabilizers was determined for a chosen increment of loading force. Displacement versus plate length curves are shown in figures 7 and 8. Displacements in the plate's longitudinal plane were analyzed for both extension load and compressive load (figure 7). For a torsional moment, displacements in the transverse plane were

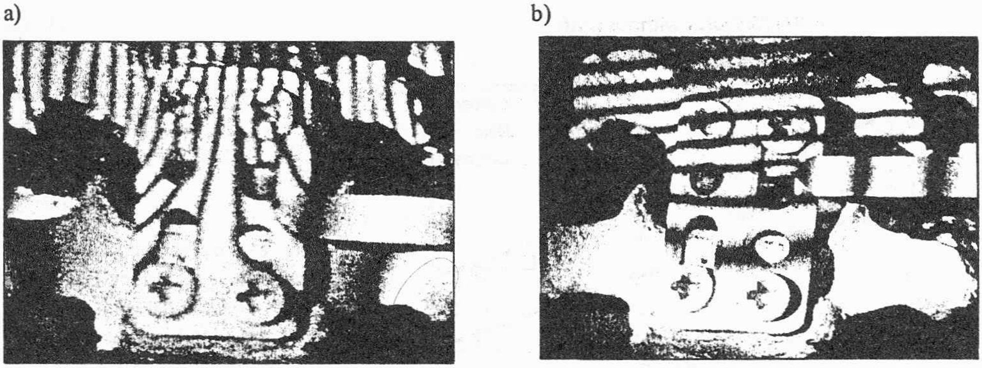


Fig. 6. Holographic interferogram: a) rotation, b) compression

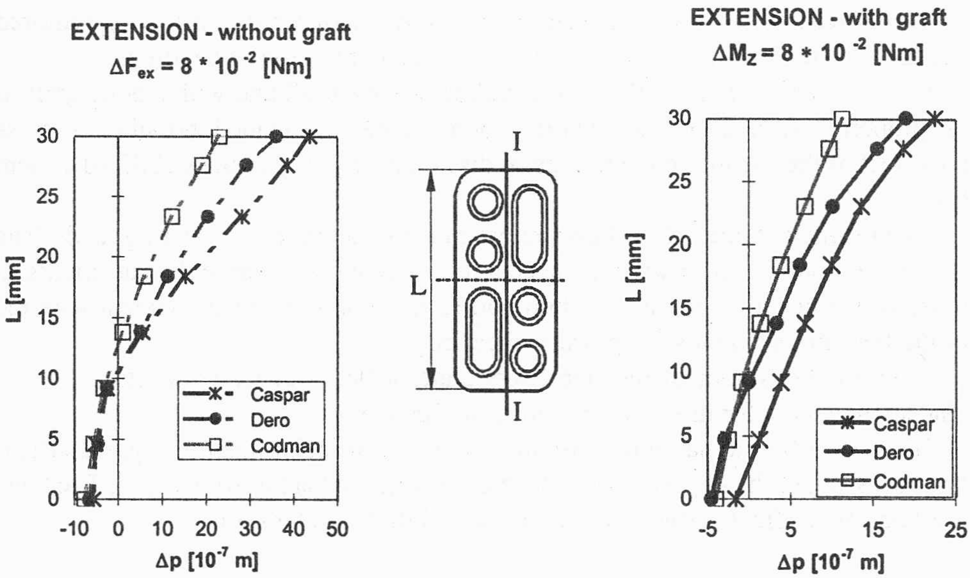
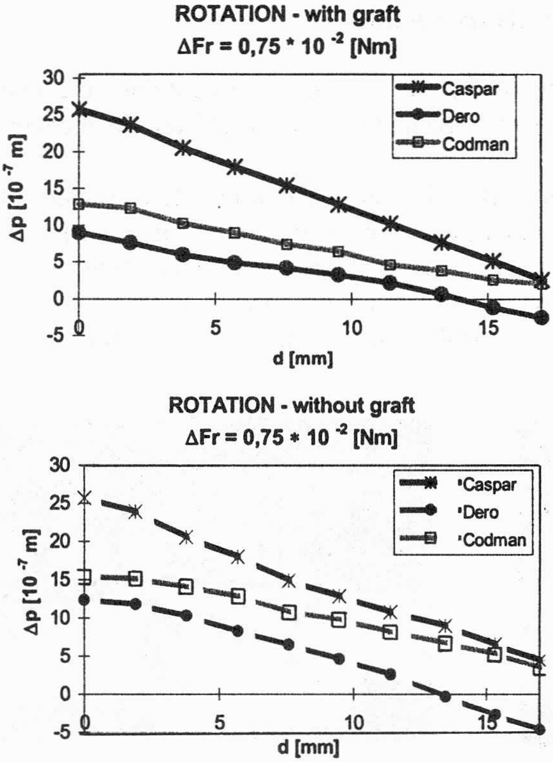


Fig. 7. Displacements in the plate's longitudinal plane (I) for an extension load, constant load $F_{ex} = 1$ Nm, load increase $\Delta F_{ex} = 8 \cdot 10^{-2}$ Nm



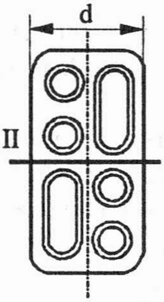


Fig. 8. Displacements in the plate's transverse plane (II) for a rotation load, constant load $F_r$ = 0.15 Nm, load increase $\Delta F_r$ = $0.75 \cdot 10^{-2}$ Nm

analyzed (figure 8) since the interference pattern characteristic of torsion required a slightly different approach than in the case of compression or bending.

Curves were plotted for the model without a bone graft and with a bone graft of the properties similar to those of normal bone tissue. This made it possible to assess the effect of the substitute intervertebral disc on the rigidity of the stabilized system [9].

The results obtained show how important the bone graft is in bearing loads. The system without a bone graft is subjected to nearly twice as large displacements as those which occur when the vertebral bodies are supported by an element with the properties similar to those of physiological bone.

Then the behaviour of the stabilizers under a torsional load was studied. Displacement curves for this case are shown in figure 8.

It can be inferred that in the case of torsion, the articular junctions on the articular processes are the key elements which determine the load bearing mode. The bone graft has poor effect on the mobility of the stabilized system [9].

## 5. Summary

It should be noted that the system without a bone graft (simulation of the conditions in a few days after the introduction of a bone graft when it does not participate in load bearing) contributes to a considerable increase in the displacement of the stabilized motor segment. This suggests that such a configuration is less advantageous to treatment, especially if no union of fragments occurs over a longer period of time, which may lead to a secondary destabilization of the damaged spine segment.

The differences in the performance of the plate implants were also due to the design of the stabilizer and the material from which it was made. This was demonstrated by determining the rigidity parameters of the stabilizers considered (the table). Implants made of a titanium alloy had much lower rigidity. However, comparing two stabilizers, i.e. Caspar and Codman, made of the same material based on titanium one can find that geometric features, which in the Codman plate enhance its rigidity, have a significant influence on the rigidity characteristics.

Based on the comprehensive experimental and numerical investigations carried out on the constructed models the following goals have been reached:

1. A detailed analysis of a three-dimensional state of strain – one of the major parameters of mechanical analysis enabling an assessment of the load bearing mode in a motor segment, and consequently providing an additional instrument for determining the causes and pathomechanism of injuries sustained during implantation treatment and failures of such treatment in the clinical practice.

2. An analysis of the state of displacements – a basis for both qualitative and quantitative comparison of different types of plate stabilizers (made for a few selected schemes of loading) and their effect on the rigidity of the whole motor segment and consequently on the overloading of the other part of the cervical spine.

3. It has been established beyond all doubt that the stabilizer's rigidity associated with the plate's design and arrangement of screws affects the state of displacements and strains resulting from different patterns of loads in the spine's segment. Therefore guidelines for the use of the stabilizers considered should be drawn up. It has been found that the distribution of strains in the stabilized region affects the durability and stability of the union between the implant and the stabilized section of the spine. Due to an optimum stabilizer the growth of bone tissue (vertebral arthrodesis) in the region of injury should be faster than the "negative remodelling" (bone atrophy) around the inserted screws.

## 6. Conclusions

The research on the phenomena associated with the insertion of a fixating device into spinal structures and on the effect of particular fixation systems, including that of their rigidity and design features, upon the behaviour of the stabilized segment under physiological loads is still inadequate. Several clinical reports point to the benefits resulting from the use of plate fixators. At the same time there are many reports on failures in the treatment despite all positive clinical indications. Therefore it seems necessary to investigate certain parameters which may affect the quality of fixation, the course of treatment and the permanence of implantation and which cannot be assessed on the basis of clinical trials only. This gives a good reason for comparative studies of the most popular fixators and for determining the effect of particular fixator designs with known rigidity on the state of strain in the bone tissue or in the soft tissues. Many researchers, not only in the field of spine biomechanics, emphasize that it is highly important to supplement clinical observations with a detailed biomechanical analysis. In the case considered, both a systematic experimental study and a thorough numerical analysis allowed us to extend our knowledge of the phenomena associated with the mechanics of the cervical spine–fixator system.

The results obtained were compared with clinical assessments of the effects of cervical spine stabilization procedures performed in different centres in Poland. It should be emphasized that a choice of an implantation system and the way it is introduced depend on the operator's experience. All kinds of complications and failures in the treatment are reported in the spondylorthopaedics literature and at specialistic conferences. The most common factors causing complications in spine implantation include:

1. Ill-matched mechanical properties of the fixator.
2. Ill-matched rigidity and deformation properties of the implant's elements.
3. Errors in the assembly of the fixator.
4. Aggressive and allergic reactions of the human body resulting in intolerance to the implant and in its rejection.
5. Surgeon- and procedure-unfriendly instruments.
6. Ignorance of the basics of spine biomechanics in the physiological condition and with fixators inserted in the spine.

Therefore implants should be approved for use on the basis of a broad assessment of their clinical and biomechanical properties, including strength, deformation, durability, corrosion resistance and biotolerance aspects.

## References

[1] ABITBOL J.J., ZDEBLICK T., KUNZ D., MCCABE R., COOKE M.A., *Biomechanical Analysis of Modern Anterior and Posterior Cervical Stabilization Techniques*, Proceedings of the American Academy of Orthopaedic Surgeons, 1994, pp. 10–11.

[2] *Experimental analysis of strain and stress*, ed. by Z. ORŁOŚ, PWN, Warsaw, 1977.

[3] BĘDZIŃSKI R., *Biomechanics Engineering, Selected Problems*, Wrocław University of Technology, Wrocław, 1997.

[4] CLAUSEN J.D., GOEL V.K., TRAYNELIS V.C., RYKEN T.C., ZHENG Z., ROACH R.M., *Biomechanics of Caspar and Synthes plates in quasi-static and cyclic loading models*, BED 24 Bioengineering Conf., 1993, pp. 618–20.

[5] COE J.D., WARDEN K.E., SUTTERLIN C.E., MCAFEE P.C., *Biomechanical evaluation of cervical spinal stabilization methods in a human cadaveric model*, Spine, 1989, No. 14, pp. 1122–1130.

[6] GRUBB M.R., CURRIER B.L., BONIN V., GRABOWSKI J.J., *Biomechanical evaluation of anterior cervical stabilization in a porcine model*, Transactions of the 39th Meeting of the Orthopaedic Research Society, 1993, pp. 714.

[7] KOTANI Y., CUNNINGHAM B.W., ABUMI K., MCAFEE P.C., *Biomechanical analysis of cervical stabilization systems*, Spine, 1994, Vol. 19, No. 22, pp. 2529–2539.

[8] MALCA S.A., ROCHE P.H., ROSSET E., PELLET W., *Cervical interbody xenograft with plate fixation: Evaluation of fusion after 7 years of use in post-traumatic discoligamentous instability*, Spine, 1996, Vol. 21, No. 6, pp. 685–690.

[9] PEZOWICZ C., *Analysis of overload mechanics and the human cervical spine fixation*, Ph.D. dissertation, University of Technology, Wrocław, 1999.

[10] RICHMAN J.D., THOMAS E.D., ANDERSON D.D., MILLER P.L., DOUGLAS R.A., *Biomechanical evaluation of cervical spine stabilization methods using a porcine model*, Spine, 1995, Vol. 20, No. 20, pp. 2192.

[11] SHEA M., EDWARDS W.T., WHITE A.A., HAYES W.C., *Variations of stiffness and strength along the human cervical spine*, J. Biomechanics, 1991, Vol. 24, No. 2, pp. 95–107.

[12] SPIRAKIS A., LEARMANTH L.D., GRYZAGORIDIS J., *The use of holographic interferometry in the assessment of orthopaedic implants*, Experimental Mechanics, Technology Transfer between High Tech. Engineering and Biomechanics, ed. by E.G. LITTLE, Amsterdam, 1992.

[13] SUTTERLIN C.E., MCAFEE P.C., WARDEN K.E., REY R.M., *A biomechanical evaluation of cervical spine stabilization methods in a bovine model*, Spine, 1988, No. 13, pp. 795–802.

[14] TRAYNELIS V.C, DONAHER P.A., ROACH R.M., KOJIMOTO H., GOEL V.K, *Biomechanical comparison of anterior Caspar and three-level posterior fixation techniques in a human cadaveric model*, J. Neurosurg, 1993, No. 79, pp. 96–103.

[15] ULRICH C., WORSDORFER O., CLAES L., MAGERL F., *Comparative study of stability of anterior and posterior cervical spine fixation procedures*, Arch. Orthop. Trauma Surg., 1987, No. 106, pp. 226–231.

[16] WEIS J.C., CUNNINGHAM B.W., KANAYAMA M., PARKER L., MCAFEE P.C., *In vitro biomechanical comparison of multistrand cables with conventional cervical stabilization*, Spine, 1996, Vol. 21, No. 18, pp. 2108–2114.

*This work was supported by the State Committee for Scientific Research, grant No. 8 T07B 011 21.*