Application of FEM for modeling of cervical spine injury as supportive diagnostic method

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1. Introduction

Cervical spinal cord injury is one of the most devastating and dangerous types of failure in modern medicine. From the other hand knowledge of forces, accelerations and muscle forces acting during accidents as well as results in tissue damage is highly limited. Information about accident circumstances can be collected by experimental crash-tests or by numerical modeling [1]. In the case of tissue damage estimation however it is exists necessity of development of new diagnostic techniques and tools allowing predict patient neurological conditions during the treatment period. One of the most promising method allowing estimation of tissue damage on the base of calculations of stress and strain numerical calculation is FE modeling. The main aim of this project is to develop individual FE models allowing calculations of displacement, stress and strain levels in spinal cord tissues of real patients and correlate them with patients neurological conditions. The range of project consists selection of patients of Neurological Department in Wrocław Medical University, MRI examination, measurement of cervical spinal cord geometry and geometry of injury, development of procedure for automatic FE model development, analysis of strain and stress distribution, preliminary correlation of those mechanical parameters with neurological conditions of patients.

2. Methods

Group of patients were completed by preliminary estimation of patient conditions. Second selection criterion was type of failure to assure wide range of cases. Each patient was examined by MRI and DTI methods. For each patient all important geometrical dimensions of grey and white matter were measured on MRI scans of cervical cord cross-sections. Geometrical parameters of cervical lordosis also were measured. Geometrical models were created on the basis of procedure written using APDL language, which allow automatically create full geometrical model on the base of previous measurements. Models were discretised using hexa-hedra type elements with 20 nodes and 3 degrees of freedom at each node (for grey matter and white matter), shell quadratic elements with 8 nodes and 3 degrees of freedom at each node (for pia mater and dura mater) and with link elements with 3 nodes and 3 degrees of freedom at each node (for denticulate ligament). Final FE model is shown at fig. 1a.

![Fig. 1](image-url)

Fig. 1 a) FE model of spinal cord, b) estimation of model load by examination of MRI scans

Grey matter and white matter were modeled as a linear isotropic materials. Values of mechanical properties were found in literature [3]. Dura mater and pia mater were modeled as orthotropic non-homogenous materials. Seven regions along cervical spine main axis were established according to the levels of vertebrae. For each level value of mechanical properties were estimated on the base of previous testing of both tissues samples [2]. Denticulate ligament was modeled as a complex of thin layer of dura mater and bunch of collagen fibers. Mechanical properties for link elements were taken as a properties of collagen [4].
Mechanical load (nodal displacements) for each model was estimated on the basis of movement range of bone parts or soft tissue in spinal column measured on the MRI scans (fig. 1b). In the other words, it was assumed so only permanent loading coming from spine failure acts on the spinal cord. Model was verified by comparison of displacement distribution form numerical calculation and from experimental measurements of real cervical spine samples.

For each patient from selected group individual model was created and individually loaded by displacements of nodes according to estimation of bone and soft tissue failure. Strains distributions were estimated on the level of most deformed cross section and on the sagittal cross-sections of whole model.

3. Results

On the most deformed horizontal cross-section in each model strain values were analyzed in previously defined sub-areas separately. Each sub-area is a region in which exists nervous tracts responsible for function described in neurological state test. Because of that it was possible to analyze possible influence of strain values on physiological functions of injured patient. Exemplary distribution of $\sigma_x$ stress component is presented on the Figure 2b. Results shows that main tissues carrying load in the injury conditions are dura mater and pia mater. Maximal values of components of stress state always were recorded on the surface of spinal cord. However the maximal values of components of strain state were recorded in the volume of grey matter and white matter. Exemplary distribution of $\varepsilon_x$ strains in the sagittal cross-section is presented on the Fig. 2b.

![Fig. 2](image)

Fig. 2 a) results of DTI examination, b) distribution of $\sigma_x$ c) distribution of $\varepsilon_x$

Results of stress and strain analysis were also compared with results of new technique of tomography – DTI, which allow to observe disturbances of function of nervous tracts. Comparison shows so, especially in case of strains distribution regions of maximal values of strains in grey and white matter corresponds with regions of nervous tracts.

4. Discussion

Preliminary results of investigations shows that strain distribution analysis could be a valuable method of estimation of range of cervical spinal cord injury (mechanical damage of tissues). Information about injury obtained in very first time period after injury is priceless information necessary for treatment planning. In case of fast automatic FE models development it is exist possibility of use of that method also in clinical conditions. Method could be also combined with novel techniques of tomography (such DTI) and extend widely capabilities of injury diagnostic. Analysis of stress and strains distribution using FE models allows also better understanding of co-operation of tissues in load transfer process.

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References